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MOBILITY ENVIRONMENTAL RESEARCH STUDY
ONE-PASS PROGRAM

January, 1965

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by PETER W. HALEY

LAND LOCOMOTION LABORATORY

ATAC

COMPONENTS RESEARCH & DEVELOPMENT LABORATORIES

U.S. ARMY TANK AUTOMOTIVE CENTER WARREN, MICHIGAN

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MOBILITY ENVIRONMENTAL RESEARCH STUDY

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Peter W. Haley

January, 1965

Project No: 5900.21.73302 ARPA ORDER NO: 400

LAND LOCOMOTION LABORATORY

ABSTRACT

The test program was divided into four parts, based on the soil conditions considered:

1. Determination of the coefficient of friction between the vehicle wheel or track and a slippery surface overlaying a hard pan of silty clay and one of Buckshot Clay, through measured vehicle tests and predicted performance.

2. Determination of the drawbar-pull vs slip curve in a fat Buckshot Clay for the vehicles tested by measured vehicle tests and predicted performance.

3. Determination of the drawbar-pull vs slip curve in a lean silty clay for the vehicles tested by measured vehicle tests and predicted performance.

4. Determination of the drawbar-pull vs slip curves for an Euclid C-6 crawler tractor in (1) a dry sand and (2) a slippery surface condition on a clay by means of a measured vehicle test and predicted performance.

These vehicle tests were performed with a single pass through the undisturbed test course. The vehicles chosen represented a wide range of standard military vehicle characteristics using a minimum number of vehicle types. The choice of vehicles included a ¼-ton M38A-1, 3/4-ton M37, 2-1/2 ton M35A1 (modified to single 11.00 - 20 tires), M29C Amphibian, M116 Personnel Carrier and a POLECAT 914 Articulated Steering vehicle.

The test results are discussed in terms of the accuracy of predicted vehicle performance. Particular emphasis is given to causes of differences between predicted and measured performance values. A strong suggestion, based on observation of the tests is offered for more properly conducted vehicle tests and soil measurement techniques.

ACKNOWLEDGEMENT

This program was conducted by the Land Locomotion Laboratory of ATAC in association with the Army Mobility Research Branch, Waterways Experiment Station, U. S. Army Corps of Engineers under the Mobility Environmental Research Study Project and the sponsorship of the Office, Secretary of Defense, Advanced Research Projects Agency, AMCMS Code 5900.21.73302, ARPA Order No. 400.

LIST OF FIGURES

TABLE OF CONTENTS

INTRODUCTION

The One-Pass Mobility Study was one of several programs initiated to fit into the scope of the MERS Development of a Quantitative Cross-Country Mobility Prediction System. It was designed to determine or improve the soft soil vehicle relationships for: (a) minimum soil strength requirements for self-propelled and maneuvering operations, (b) drawbar-pull vs slip at minimum soil strength requirements, (c) speed performance relations for soil strength in excess of minimum requirements, and (d) surface traction for maximum attainable slippery conditions.

Participation in this program by the Land Locomotion Laboratory was oriented toward the drawbar-pull vs slip and surface traction predictions. The Land Locomotion Laboratory's system for vehicle performance prediction in soft soil conditions is basically summed up in terms of the drawbar-pull which a vehicle could develop in surface soils. The soil-vehicle relations used are applied to the case of the vehicle sinking or the case of the vehicle being supported at the surface. As a result, the surface traction and soft soil portions of this program fit well into the scope of the Laboratory's purpose for participation.

In reviewing the test results of this program, an awareness of the capabilities of predicting performance along with the limitations imposed on the present system is necessary to derive any meaning from the curves obtained. The soil-vehicle prediction system in essence provides the maximum attainable performance that a vehicle could develop for a given soil condition. The obvious statement that follows is: the influence of any exterior element or elements for which the system, in its present form, is incapable of describing quantitatively can and often times adversely affects both the actual and predicted performance of the vehicle. It should suffice to say that for those test results in which the level of accuracy achieved was acceptable, there is an apparent minimal presence or lack of exterior elements affecting the accuracy of the prediction system. Of primary importance and also the main objective of this program is the improvement of the present system for both prediction and testing procedures in terms of those results which were unsatisfactory. Through observation of the vehicle tests and soil tests, an explanation of the effect of extraneous conditions arising from both the actual test and soil conditions is given. In cases where a quantitative measure or control of adverse conditions is well within the feasibility of field testing, correction measures are described and strongly advised.

OBJECT

The purpose of the test program was twofold:

1. Obtain the drawbar-pull vs slip relationship for a wide range of vehicle characteristics in fine grained soft soils and high load bearing soils with a slippery surface layer on the basis of a one-pass criteria.

2. By means of the present Land Locomotion Mechanics Soil-Vehicle System, predict vehicle performance and improve the level of accuracy for the present system.

The sites chosen for performing the test program were located in the Vicksburg, Mississippi area and also the Grenada Lake, Mississippi reservoir. These areas afforded the most ideal conditions for testing both from the standpoint of soil conditions available and the proximity to the Army Mobility Research Branch, Waterways Experiment Station, U. S. Corps of Engineers as a base of operations.

The surface traction studies were performed during the months of June and July, 1964, at the Waterways Experiment Station where silt and Buckshot Clay courses could readily be prepared to provide the range of surface soil strengths desired. To obtain the effect of a full range of soil strengths, drawbar tests were performed for a hard surface condition, a flooded condition, and various drained conditions, the variable being time after drainage to testing. The vehicles involved in this series of tests were two wheeled vehicles, the M38A1 and M37 and one tracked vehicle, the M29C.

The second test site area chosen was the shore area of Lake Centennial which is adjacent to the Vicksburg area. Figure 1 shows the five areas chosen for the overall test series. Areas B, B - East and D were the sites of the drawbar pull tests in which the Laboratory participated. The Lake Centennial area was chosen owing to the deposits of a fat almost pure Buckshot Clay of fairly uniform profile for at least 24 inches of depth. The area is ideal for testing during the late summer and early fall months since the Mississippi River, the Lake's water source, is continuously receding during

this time and precipitation is at a minimum during these months. The vehicles chosen for this series of tests were the M29C (12 inch and 20 inch track), M116, and the POLECAT.

The third test site, Grenada Lake Reservoir consists of a lean silty clay overlying a hard pan which ranges in depth beneath the surface from 6 to 18 inches. The silt layer is relatively firm but fairly brittle having a plastic index range from 4 - 7. The area is very conducive to traction studies from the standpoint of almost negligible vegetation and uniformity of soil strength in the 0-3" surface layer. The vehicles chosen for this test site were the M38A1, M37, M35A1, M29C (12 inch and 20 inch track) and the POLECAT 914. Figure 2 shows the locality of Grenada Lake Reservoir and areas 9, 11, and 12, which were the sites of the drawbar tests.

SUMMARY

The tests performed under this program include only those associated with the drawbar-pull vs slip prediction in soft soil and slippery surface conditions. These tests were performed with emphasis on fine grained soils, except one test which was performed with an Euclid C-6 crawler tractor in sand. Previously developed analytical expressions have been used to predict the performance of the vehicles tested. The results obtained have been evaluated on the basis of observation of the actual conduct of the test. Improved accuracy between predicted and actual results, is discussed in terms of feasibility of improving test techniques and prediction relationships.

CONCLUSIONS

Accurate predictions of vehicle performance can be achieved when the following conditions exist:

1. Soil conditions:

a. A uniform surface or a uniform layer, having a depth greater than the vehicle's sinkage or three times the track or wheel width, exists for the length of the test course.

b. There is no appreciable root vegetation affecting soil strength.

c. The soil is not sensitive to the remolding caused by wheeled vehicles in particular.

d. The course is free of shrinkage cracks affecting soil shear measurements.

The level of accuracy depends on the degree to which these conditions exist.

2. Vehicle Conditions:

a. Moving parts (sprockets, road wheels, track links, pneumatic tire treads) should be kept as clean as possible.

b. Both left and right tracks must turn at the same speed. They must be locked in the case of articulated vehicles employing such locking devices.

c. The load distribution on axles of wheeled vehicles should be known.

d. Wheel rpm counting devices should be attached to each wheel with front transfer cases engaged for all wheel drive systems.

3. Vehicle Test Procedure:

a. No steering should be employed in conducting a drawbar test on a tracked vehicle.

b. There should be minimal steering in the case of wheeled vehicles.

c. Maintenance of engine speed which develops maximum out-put torque is required.

d. Obtain as full a range of slip values in as many even increments as is possible. This procedure enables a more comprehensive comparison of predicted and actual test values. Elimination of any irregularities at a given slip due to test conditions may be achieved also.

4. Soil Measurements:

a. Shear measurements should be taken employing normal pressures in the vicinity of the vehicle's ground pressure.

b. Effect of sinkage on shear readings due to side shear effects should be accounted for quantitatively.

c. Shear measurements should be taken prior to tests and in the wheel or track ruts after the vehicle test. This procedure should be adopted where sensitivity to remolding is suspected in the case of wheeled vehicle tests.

d. Both the shear head and penetration plates should be wiped clean after each measurement.

e. A minimum number of four sets of shear readings, three penetration plate sizes, and three plate penetrations per plate should be taken throughout the length of the course for purposes of reproducibility of results.

In general, many of the above requirements were met during the conduct of the tests. However, for a variety of reasons (detailed discussion may be found in the Test Results and Evaluation portion of this report) some of these requirements were not met, which resulted in poor vehicle performance and poor prediction.

RECOMMENDATIONS

The following recommendations are made to complement the present method of field testing and analysis:

1. All wheeled vehicles should be equipped with wheel revolution counters so that each wheel can be treated separately. This procedure is necessary due to the lack of non-slip or limited

slip differentials on wheeled vehicles. The lack of limited slip differentials is due to the difficulty that would be encountered in steering if these devices were employed on the front wheel drive train.

2. The use of continuous immediate visual readout instruments only affords the instrument operator the opportunity to relay information to the vehicle drivers during the test. This procedure informs the drivers on the progress of the test and enables them to act accordingly.

3. Obtain shear measurements using normal pressures comparable to the vehicle's ground pressure. This procedure can be achieved quite readily with the new hand-operated Bevameter units.

4. Investigate the effect of normal pressure on the shear deformation modulus K by performing shear tests at high normal pressures.

TEST RESULTS AND EVALUATION

Discussion of the test results can be handled most efficiently by treating each division of the test program separately. Most of the problem areas encountered were peculiar to the type of test or soil conditions which existed and generally were not common to all divisions of the program.

Surface Traction

The first division undertaken was the surface traction studies on the prepared silt and Buckshot clay courses. The months of June and July, 1964 were the dates selected to conduct the tests on the basis of minimum rainfall in previous years. Secondly, this phase could be completed during the time inundated areas for soft soil studies became available by the receding water of the Mississippi River.

Unfortunately, the surface condition of the clay course was greatly affected by precipitation and attempts to control the surface moisture by means of a tarpaulin cover were defeated by excessive amounts of unexpected rainfall. This excess rainfall rendered the

course useless because of the time required for the surface to dry. The silt course, being less affected by precipitation, became the primary object of study.

The surface traction test results for silt are shown in Table I.

The torque developed by the engine (T.E.) less the internal resistances (R_i) determines the maximum traction which could be developed by the vehicle. However, the vehicle can never develop more traction than that defined by the shear strength of the soil (H). The lesser of the two defines the traction available in the given case. If the motion resistance due to soil deformation is called R, then the following equations hold:

$$T.E. - R_i - R = DP$$

$$H = DP + R$$

so that:

$$T.E. - R_i = H$$

Since there was no appreciable sinkage inducing soil resistance (R = O), the drawbar pull could be directly equated to the gross tractive effort (H) or to T.E.-R_i . (R_i was measured as the torque required to move the vehicle on hard ground). Unfortunately, the M38A-1 Jeep could not be equipped with a torque meter and only drawbar values could be measured. It should be pointed out that with addition of the internal resistance, R_i, the D/W values for the M38A-1 shown in Table I would show better agreement with the predicted coefficient of friction values taken with the rubber-coated annulus.

The use of a rubber annulus is realistic from the viewpoint that slipping occurs between a rubber pneumatic tire and the soil surface for the wheeled vehicles. Shear readings were taken with the grouser annulus when it was noted that the M29C track vehicle would actually dig into the surface rather than ride on its road pads.

An overall glance at Table I shows acceptable prediction for 50% of the traction tests performed. Although this value is not highly encouraging, consideration of the test conditions related below deems the results satisfactory.

The first problem encountered can be attributed to the condition of the silt course surface itself. It is the opinion of the writer that the surface layer was not sufficiently uniform to insure accurate drawbar prediction for the hard surface and for most of the drained conditions. Variation in moisture content affecting the strength was caused primarily by two factors. First, there was pooling of water due to uneven grading and second, the rate of drying was very uneven in tests where a relatively dry surface was sought. Figure 3 shows a drained condition depicting this phenomena. The rate of drying was greatly affected by the air humidity and temperature. In some instances an hour's time was sufficient to radically alter the surface strength. The difficulties encountered with the hard surface can readily be seen in Figure 4. Both the non-uniform surface layer and the lack of a very flat surface prevented the shear annulus from making full flush contact with the soil. As a result, the shear strength computed for a given normal load was less than the actual one due to an incorrect shear area value. In general, performance prediction for hard surface soil is not attempted. Hard dry surfaces do not pose the type of mobility problems which the soft soil-vehicle relationships are designed to accomodate. Consequently, the test apparatus could not be expected to perform in an environment for which it was not designed. The hard surface tests were devised merely to obtain an upper limit to a vehicle's performance.

The most uniform course was achieved for the flooded condition shown in Figure 5, and was reflected in satisfactory agreement between the vehicle test results and predicted performance. Figure 6 shows a typical drawbar test in the flooded condition.

To obtain better predicted values for the hard soil surface tests, the shear stress values occurring at the peak of the shear vs rotation curves were chosen. The surface material, being very brittle, could sustain high shear loads before encountering failure. The three vehicles tested on the hard soil surface never failed this brittle soil, but skidded along its surface. This was readily noticed in the case of the M29C which left skid marks of its road pads aft of the vehicle. Figure 7 shows a typical hard surface traction test.

From Table I it can be seen that the M29C developed considerable T.E./W for three of the drained conditions on 30 June, 1 July and 2 July. The double asterisks denote a phenomenon peculiar to this type of test. In soft soil tests, when a vehicle assumes a trim angle due to its aft section sinking the effect of sinkage can be accounted for in the predicted performance. However, in the present case, the surface could well support the vehicle and the effect of trimming was absorbed by the suspension system and the tension induced in the track. As a result of trimming, the internal resistance increased appreciably above the resistance value measured for the hard ground test and contributed a large part to the vehicle's tractive effort. Unfortunately, such a trim effect cannot be accounted for quantitatively and prediction values are apt to suffer.

Lake Centennial Buckshot Clay Tests

The second section of the test program involved drawbar tests conducted in fat Buckshot Clay along the periphery of Lake Centennial. At the time of this Laboratory's entrance into participation of the program, the wheeled vehicle tests had been completed or eliminated and only tracked vehicles remained in the test program. Of the nine tests performed, five were satisfactory and four were unsatisfactory. Four of the satisfactory tests, performed on the POLECAT in Area B - East could be deemed excellent. Figures 8, 9, 10, 11, and 12 show the satisfactory results obtained at Lake Centennial while Figures 13, 14, 15, and 16 depict unsatisfactory results.

There were four main problem areas encountered at the Lake Centennial test site which probably contributed to poor vehicle performance leading to poor correlations.

Similar to the traction studies, though different in nature, the soil conditions posed three of these problems.

First, the soil itself is very high in mineral content causing rapid growth of vegetation. Figures 17 and 18 show the grass and stubble cover encountered in some of the test areas. To avoid the vegation, drawbar tests were confined to areas adjacent to the

water's edge as much as possible. This line of action greatly reduced the amount of exposed surface area available as test lanes. Attempts were made to cut down the grass covering these areas, but the low-bearing strength of the soil caused numerous immobilizations of the clearing vehicle.

Confinement to the water's edge in Area B-East created a second problem of space conservation and the presence of a soil strength gradient. It was decided that to obtain drawbar data for all of the vehicles to be tested, test lanes should be made perpendicular to the water's edge to conserve space. This procedure enabled drawbar tests to be performed on all of the vehicles but overlooked the fact that a strength gradient existed over the length of the test course. In point of fact, during the conduct of the test on the POLECAT, it was noted that this vehicle's overall length spanned a wide range of the soil strength gradient. Consequently, shear measurements had to be taken at the extreme ends of the test course (test letters A & E on the curves) where the strength of the soil was either at its weakest or strongest value. Furthermore, only the end point vehicle test values could be compared to the predicted curve if any reasonable agreement was to be expected. The end point vehicle test values being few in number almost made for a hazardous guess of the accuracy that could be expected in predicting them. Again, it is the opinion of the writer that a more efficient test procedure would have been to run parallel to the water's edge and possibly eliminate a few vehicles for the sake of more uniform test lanes.

Thirdly, in all of the areas tested, there existed a surface condition which was unsatisfactory for obtaining reliable shear readings with the Bevameter annulus. Being a fat clay and exposed to continuous drying, shrinkage caused cracks which extended 2 - 3 inches beneath the surface. Figure 19 shows the extent of crack propagation over a typical test lane. Due to these cracks, the area of soil being sheared by the annulus did not have complete lateral confinement, and even though the vehicle track was exposed to the same phenomenon, confinement was incomplete only along the track edges; whereas for the annulus, confinement was incomplete over a greater percentage of soil being sheared.

Lastly, it was noted for very weak soil strength the M29C and M116 prediction values were in error by as much as 300% of the actual vehicle data and the prediction was higher than actually achieved. In no case was the predicted performance higher than 0.3 of the vehicle's weight. It is quite conceivable that the amount of resistance the vehicles encountered (attributed to soil packing up in sprockets, road wheels, tracks and between moving parts and the hull) could account for possibly 600 lbs., which for the M29C amounts to ten percent of the vehicle's weight. This type of motion resistance cannot be determined analytically and the quantitative guess made above is the only resort available. Admittedly this is very unscientific, but the only reliance available is through visual observation and a value judgement by the observer. In short, the present system is at a loss when this kind of situation occurs.

Grenada Lake Silt Tests

The Grenada Lake reservoir area was formed approximately 15 years ago when the Yalobusha River was dammed up as a flood control measure protecting the Yazoo Valley. The area had previously been farmed and the presence of a hard pan beneath the surface has been attributed to reworking of the soil when farmed. In the past 15 years, however, a layer of silt 6 to 18 inches deep had been deposited over this hard pan creating a very uniform surface layer. The areas exposed by the receding waters of Grenada Lake remained relatively free of any root vegetation, providing excellent areas and sufficient time for drawbar tests to be performed before vegetation appeared.

In general, past test evaluation involving both wheeled and track vehicles has shown that greater accuracy can be achieved for predicting tracked vehicle performance than for wheeled vehicle performance. This trend existed for the bulk of the tests performed at Grenada Lake and the reasons for poor wheeled vehicle performance prediction were similar to those of the past. Figures 20 - 28 show the tracked vehicle results while Figures 29 -37 show the wheeled vehicle results.

One of the two main problems stem from the lack of uniform slip encountered by all driving wheels. From visual observation alone it could be seen that for any vehicle test, all the wheels were not pulling in unison. Since the prediction system assumes equal output from all driving wheels, accuracy could suffer by as much as 50% due to an effort by only half the driving wheels.

The second problem of great concern was the effect of remolding by the leading wheels of a vehicle. If the soil is sensitive to remolding, then each succeeding set of wheels encounters a soil strength of lesser magnitude than the preceding set. The more wheels on a vehicle, the greater is the effect of remolding. From the results of the self-propelled tests conducted in the areas where drawbar tests were performed, it can be concluded that the surface layer was very sensitive to remolding. In most of the self-propelled tests on the M37 and M35A1 it was noted that the surface soil could sustain one or two passes of the vehicle with negligible sinkage resulting. On the next pass, the vehicles would sink as much as 12 inches thus confirming the suspicion of a highly sensitive soil surface. As stated above a sensitive soil and an increase in the number of wheels substantially affects vehicle performance. Figure 36 illustrates this effect very vividly. This curve for the 6 x 6, M35A1 in Area 9 shows the vehicle actually becoming immobilized at approximately 21% and 24% slip, at which point it could develop no drawbar-pull due to considerable sinkage. It might also be noted that Area 9 was the weakest of the three areas, due to its proximity to the water's edge.

A problem which was rather minor in the first series of tests but which grew in magnitude during our four week stay at Grenada was the development of a grass mat over the test areas. Towards the latter part of October this mat had developed sufficiently to strengthen the soil surface, and its affect is reflected in the test results obtained for the POLECAT in Area 12. It is known that root vegetation strengthens soil structure, but its extent cannot be detected by the Bevameter annulus.

The only remaining issue that may be of interest concerns the shear deformation modulus K and the normal pressures used to obtain shear stress values. The limiting normal pressure that can be applied to the shear apparatus is of the order of magnitude of 6 psi. Most wheeled vehicles even at low tire inflation pressures exhibited ground pressures in excess of 15 psi and can be as high as 27 psi. Under high ground pressures the amount of deformation required to cause full shear failure increased and it may be that, for the small contact length encountered with the wheeled vehicles, development of the maximum shear strength of the soil was never achieved even at 100% slip. However, it is suspected that the deformation modulus becomes

asymptotic at a certain normal pressure. If this normal pressure is found to be reasonably small, say 15 psi or less for various types of soils, then it might be more realistic to take shear readings at pressures which yield a more correct shear deformation modulus compatible with the high normal pressure associated with wheeled vehicles.

The merits derived from the overall program cannot be viewed in terms of the degree of accuracy achieved for predicting performance of the vehicles tested alone. The realization and understanding of what constitutes a problem area coupled with solutions which are feasible and engineering-wise sound, should lead to better performance prediction and ultimately a more correct method of vehicle evaluation.

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TABLE I.

SURFACE TRACTION RESULTS		VEHICLE TEST T.E/W			PREDICTED VALUE Coefficient of Friction		Cohesion p.s.i.
DATE	COURSE CONDITION	M29C	M37	(D/W) M38A-1	RUBBER	GROUSER	C
16 June	Hard dry	.71	.75	-	*.41 .60 (μ_p)	.51 .87 (μ_p)	0
23 June	Flooded	.35, .38	(D/W) .18	.22	.29		0
26 June	Flooded	$\underbrace{.27, .42}_{.35}$	.16	.15		.36	0
26 June	1 hr. Drain	.31	.20	-	.29		0
30 June	12 hr. Drain	**.45	.18	.10	.32	.33	0
1 July	Poor cond. 48 hr. Drain	**.52	.26	.19	.40		.24
2 July	Hard, Dry Rolled	**.86	.67	-	*.41 .60 (μ_p)	.51 .87 (μ_p)	0
6 July	Graded, Roll Flooded, 2 hr. Drain	.31	.23	.22	.33	.33	0
10 July	Graded 24 hr.Drain Aft. Hvy. Rain	.56	.35	.33	.35	.40. .50***	.11

μ_p = Obtained from peaks of shear readings.

*Shear head not in full contact with soil surface due to hardness of surface.

**Considerable apparent motion resistance (possibly due to track tension and appreciable vehicle trim).

***Tractive effort equation for M29C.

APPENDIX I

EUCLID C-6 TRACTOR EVALUATION

As a separate exercise, but similar in nature to the one-pass performance tests conducted in Mississippi, drawbar pull tests were also conducted on an Euclid C-6 crawler tractor at the General Motors Proving Grounds at Milford, Michigan. Two test courses were prepared, one of sand and one of clay. The clay course was prepared in the same manner as the silt traction course at the Waterways Experiment Station, i.e., a slippery surface layer over a hard pan was constructed.

The test vehicle was a 21.5 ton, C-6 Tractor, a product of the Euclid Division of General Motors. The drag vehicle employed for these tests was a 50-ton dual converted ore-truck. Small percent slip values were obtained and claimed to be very accurate by the General Motors Proving Grounds personnel.

The conditions of the test courses were as follows:

1. The sand course was leveled smooth and considered dry to a depth of 3 inches. No apparent cohesion, owing to a presence of moisture, was found from the shear readings.

2. The clay course was flooded for a period of twelve hours and then drained for a period of four hours. Drawbar tests were performed at the end of the four hour drainage period.

The results of the tests are shown in Figures 38 and 39. Agreement between predicted and actual test data was very good as evidenced from the curves. The conduct of the test and course conditions were considered to be as satisfactory as can be expected for a prepared natural soil.

APPENDIX II

LAND LOCOMOTION MECHANICS EQUATIONS

The relationship used to describe the performance of the vehicles tested in this program is:

$$H = c + W \tan \phi \qquad 1 - \frac{1}{J}(1-e^{-J})$$

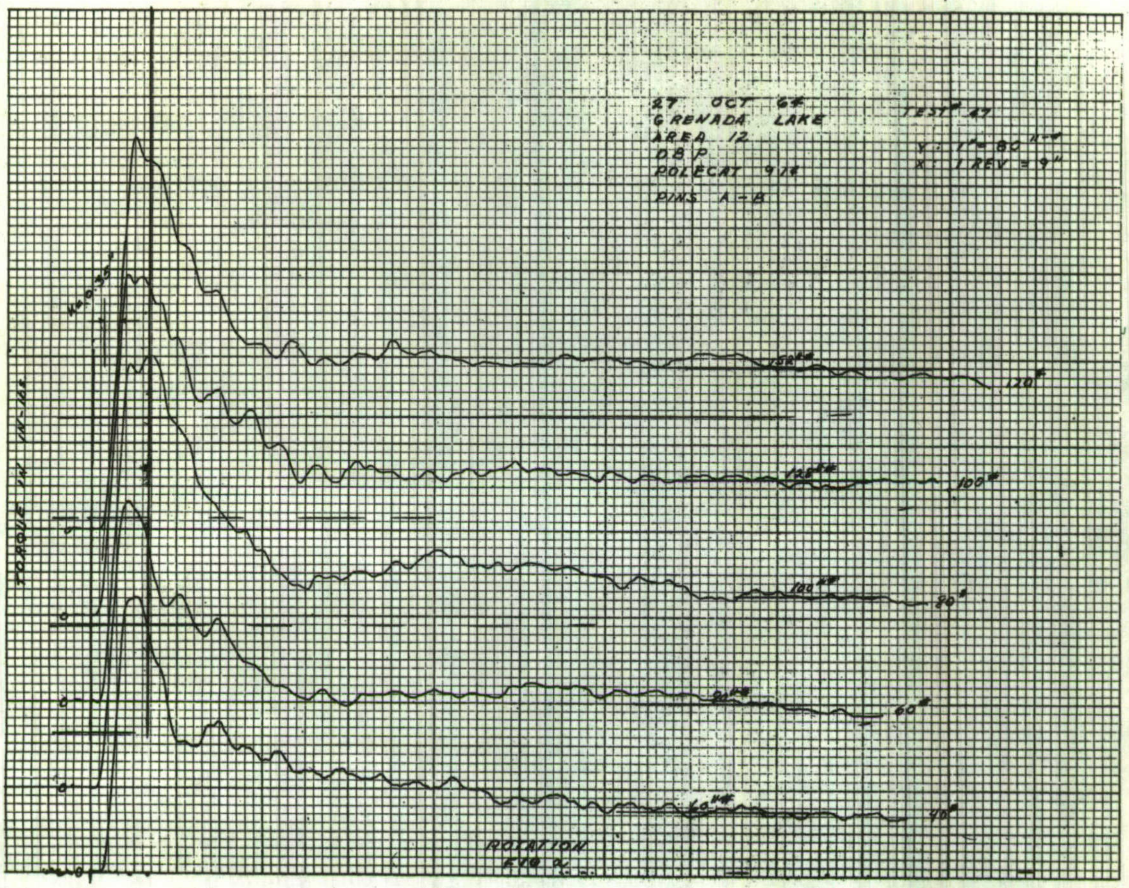
where $J = i_o\ l/K$

where

H = Gross tractive effort in lbs.
c = Unit cohesion in PSI.
W = Vehicle weight in lbs.
ϕ = Friction angle in degrees.
K = Shear deformation tangent modulus in inches.
J = Traction exponent $\frac{i_o l}{K}$
i_o = Slip ratio.
l = Contact length in inches.
e = Base of the natural logarithm.

The above equation was developed for application to tracked vehicles. At Grenada Lake no appreciable sinkage occurred for the wheeled vehicles tested and the wheel contact lengths were known. This situation allowed the equation for tracked vehicles to be used for the wheeled vehicles also. Furthermore, the relationship, DP = H-R, where R is the motion resistance due to soil compaction reduced to DP=H since R=O for zero sinkage. None of the vehicles tested at Lake Centennial, where the vehicles did sink, encountered any appreciable motion resistance.

The input soil variables c and ϕ for the gross tractive effort equation were obtained by means of the standard Bevameter annulus. An example of the field data and corresponding normal stress vs shear stress curve is shown in Figures a and b.



27 OCT 64
GRENADA LAKE
AREA 12
DBP POLECAT 914
SHEAR STRESS τ VS
NORMAL STRESS σ

TEST # 47

C = .2 P.S.I.
TAN ϕ = .36
ϕ = 19.75°
K = .32 IN.

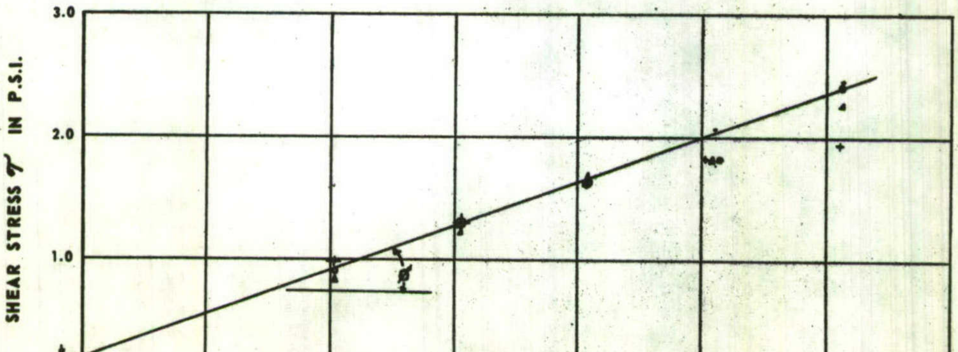


FIG. b

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Fig. 1 AERIAL VIEW OF VICKSBURG, MISSISSIPPI, MISSISSIPPI RIVER, CANAL, AND LAKE CENTENNIAL TEST SITE AREAS.

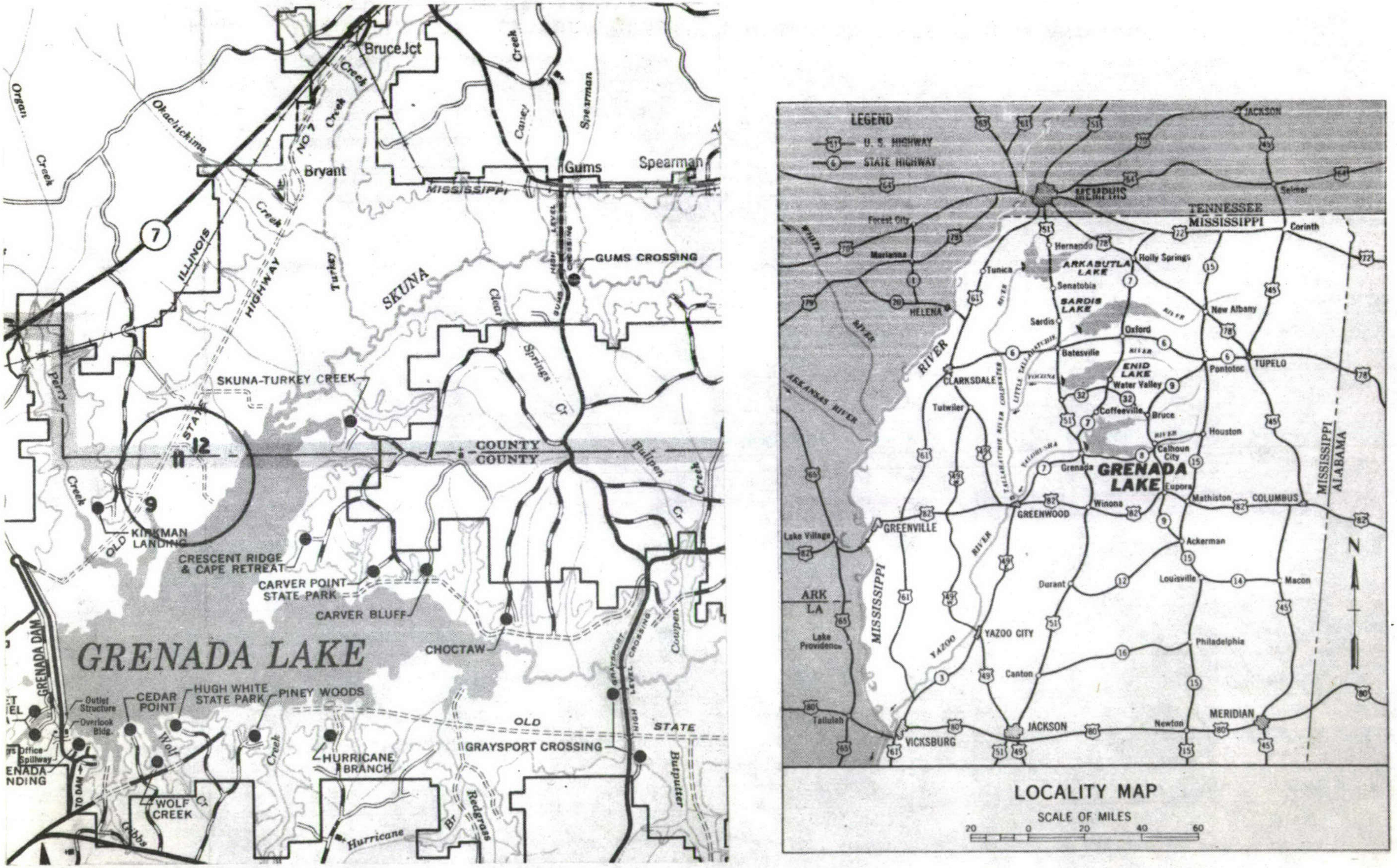


Fig. 2 MAP OF GRENADA LAKE RESERVOIR AND DRAWBAR-PULL TEST SITE AREAS 9, 11 AND 12.

Fig. 3 DRAWBAR-PULL TEST, M38A1. DRAINED SILT COURSE, WES, VICKSBURG, JUNE, 1964.

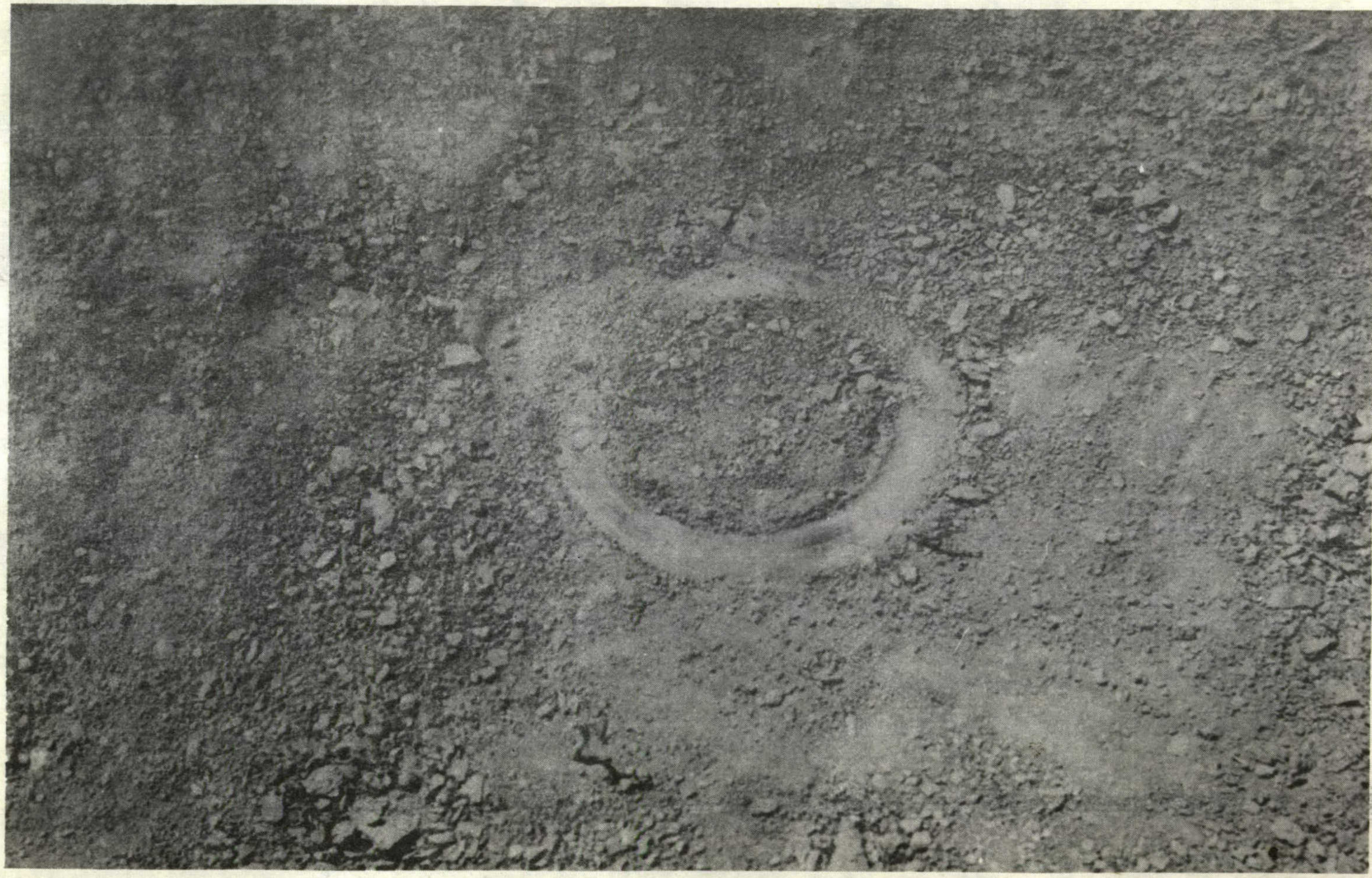


Fig. 4 SHEAR ANNULUS IMPRESSION ON HARD SURFACE, SILT COURSE, WES, VICKSBURG, JUNE, 1964.

Fig. 5 FLOODED SILT COURSE, WES, VICKSBURG, JUNE, 1964.

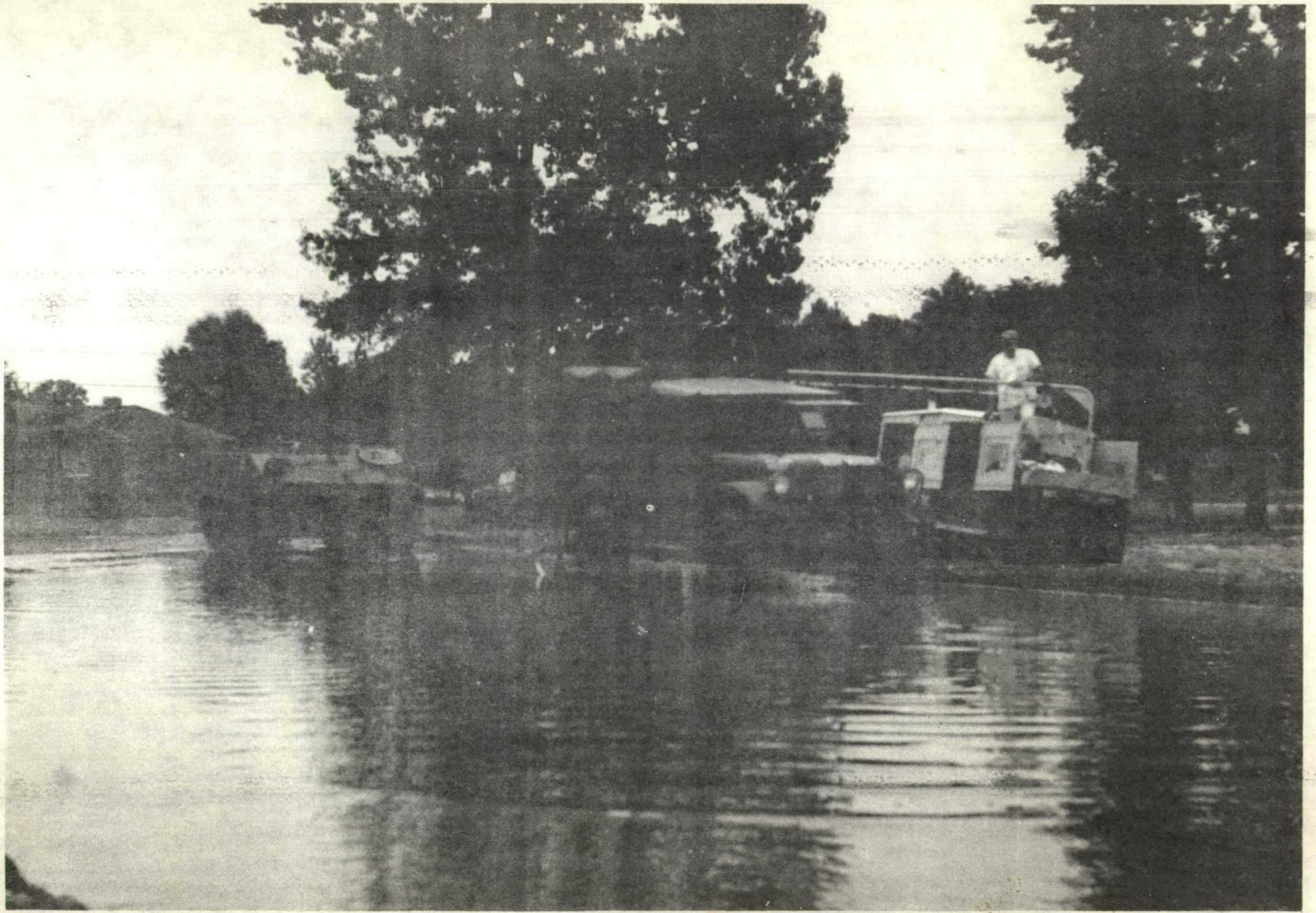


Fig. 6 DRAWBAR PULL TEST, M37. FLOODED SILT COURSE, WES, VICKSBURG, JUNE, 1964.

Fig. 7 DRAWBAR - PULL TEST, M37. HARD SURFACE, SILT COURSE, WES, VICKSBURG, JUNE, 1964.

23 SEPT 64
LAKE CENTENNIAL
AREA B EAST
POLECAT 914
DP/W VS. SLIP

TESTS # 203A, 204A

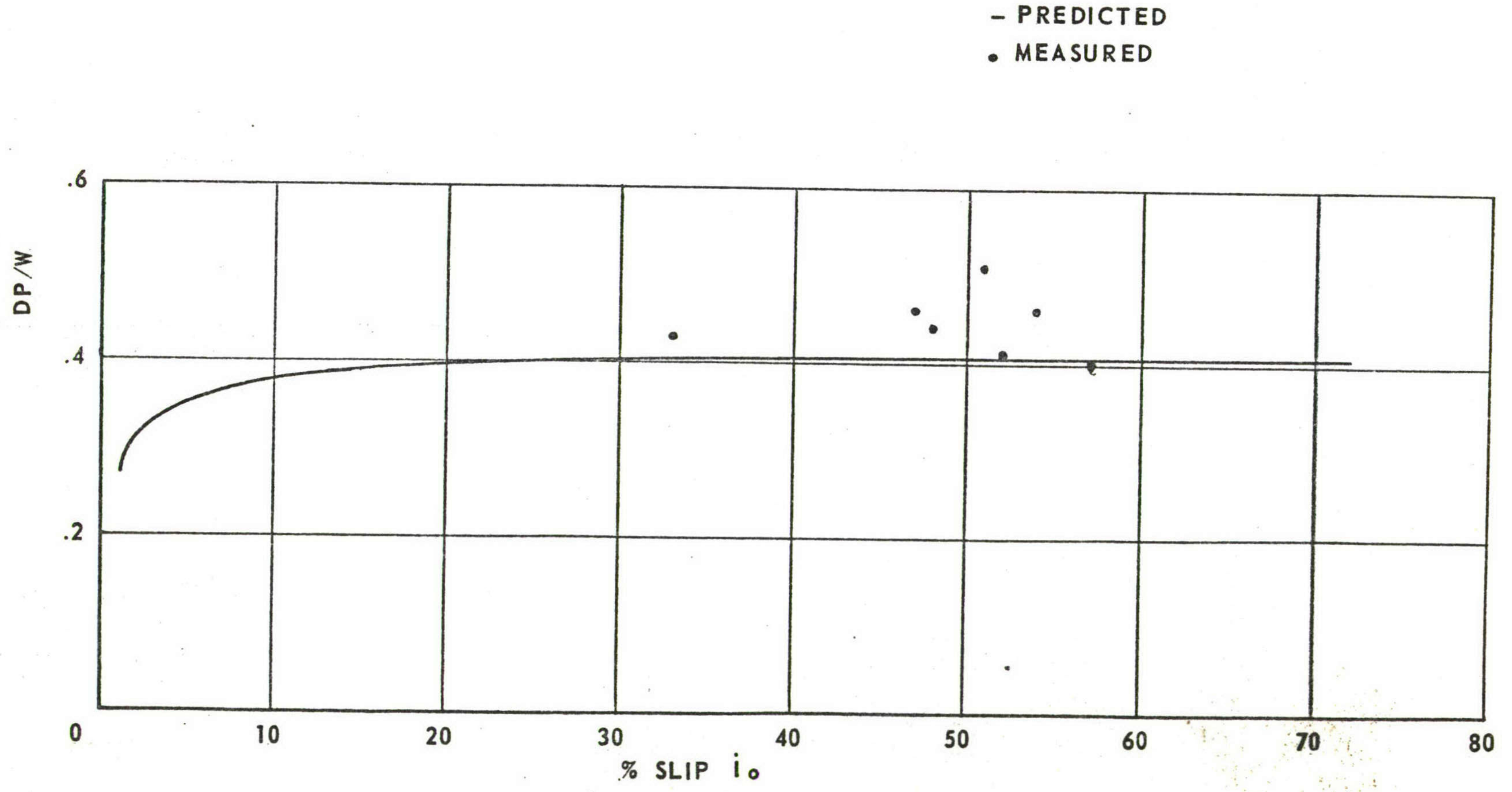


Fig. 8

23 SEPT 64
LAKE CENTENNIAL
AREA B EAST
POLECAT 914
DP/W VS. SLIP

TEST #203 E

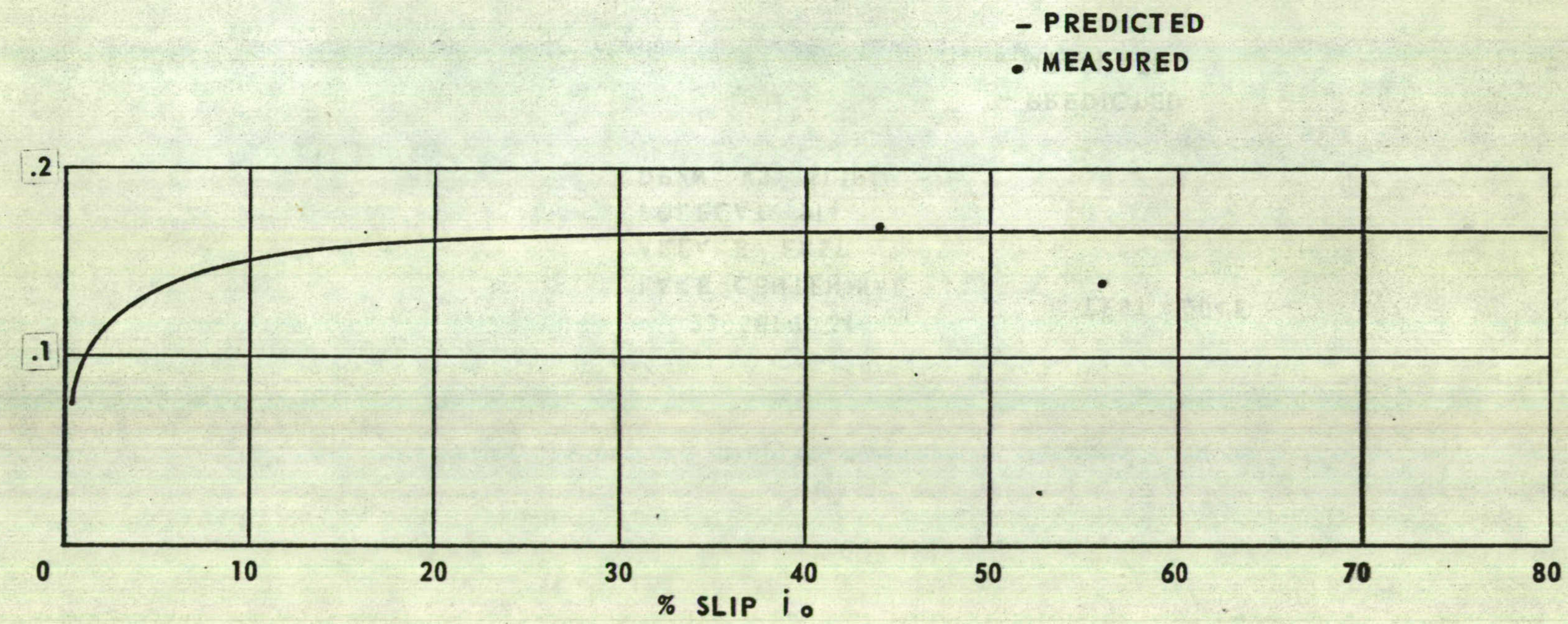


Fig. 9

23 SEPT 64
LAKE CENTENNIAL
AREA B EAST
POLECAT 914
DP/W VS. SLIP

TEST # 204 E

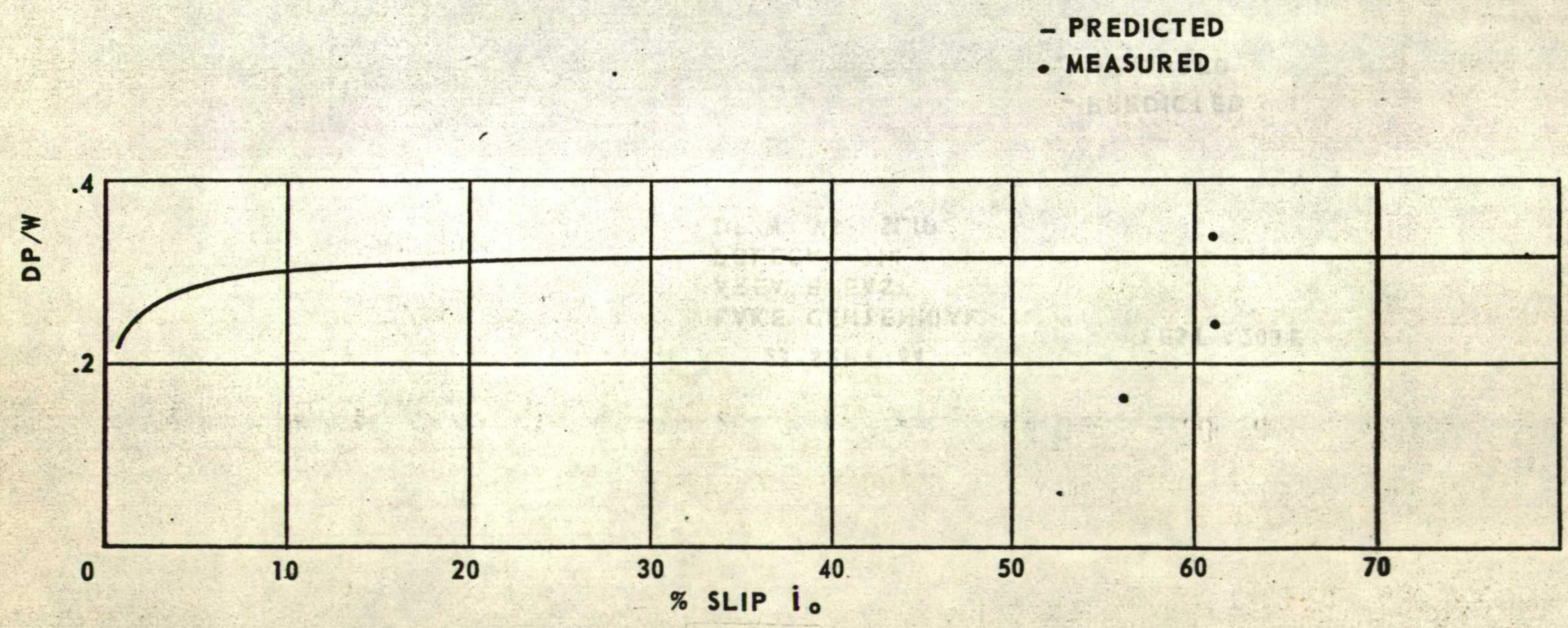


Fig. 10

23 SEPT 64
LAKE CENTENNIAL
AREA B EAST
POLECAT 914
DP/W VS. SLIP

TEST # 206 E, 207 E

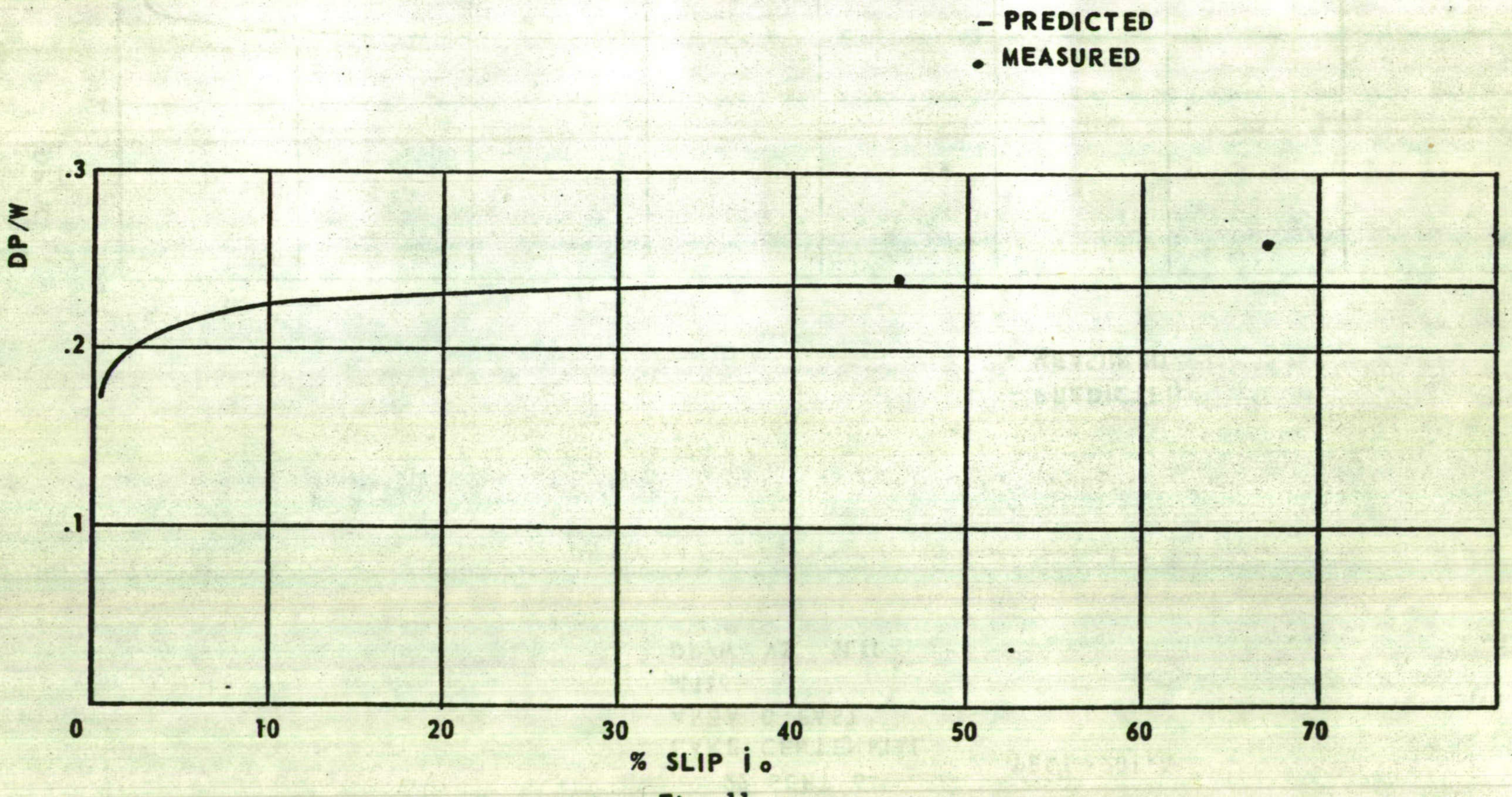


Fig. 11

22 SEPT 64
LAKE CENTENNIAL
AREA B-EAST
M116
DP/W VS. SLIP

TEST #201-A

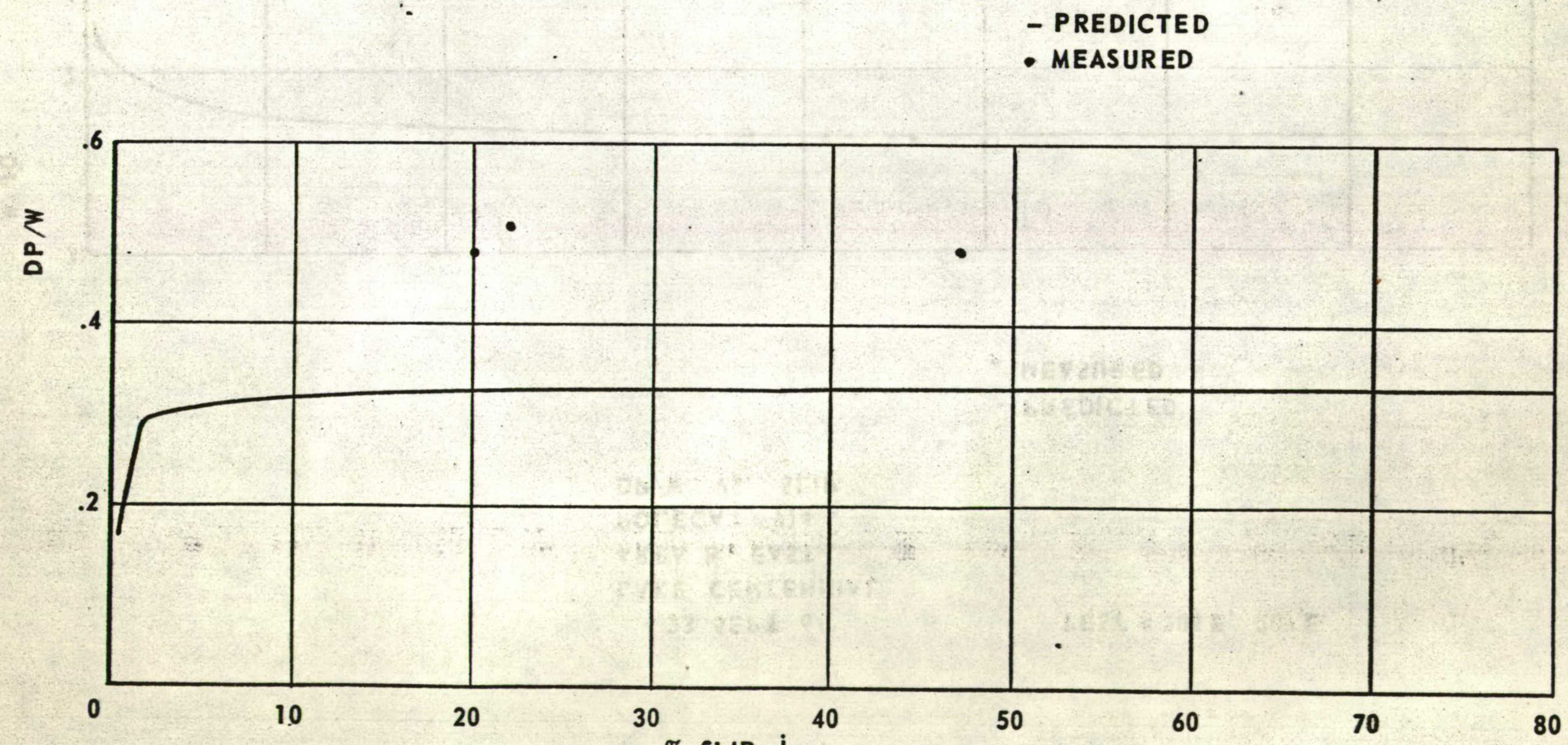


Fig. 12

16 SEPT 64
LAKE CENTENNIAL
AREA D
M 29C - 12" TRACK
DP/W VS. SLIP

TEST #181

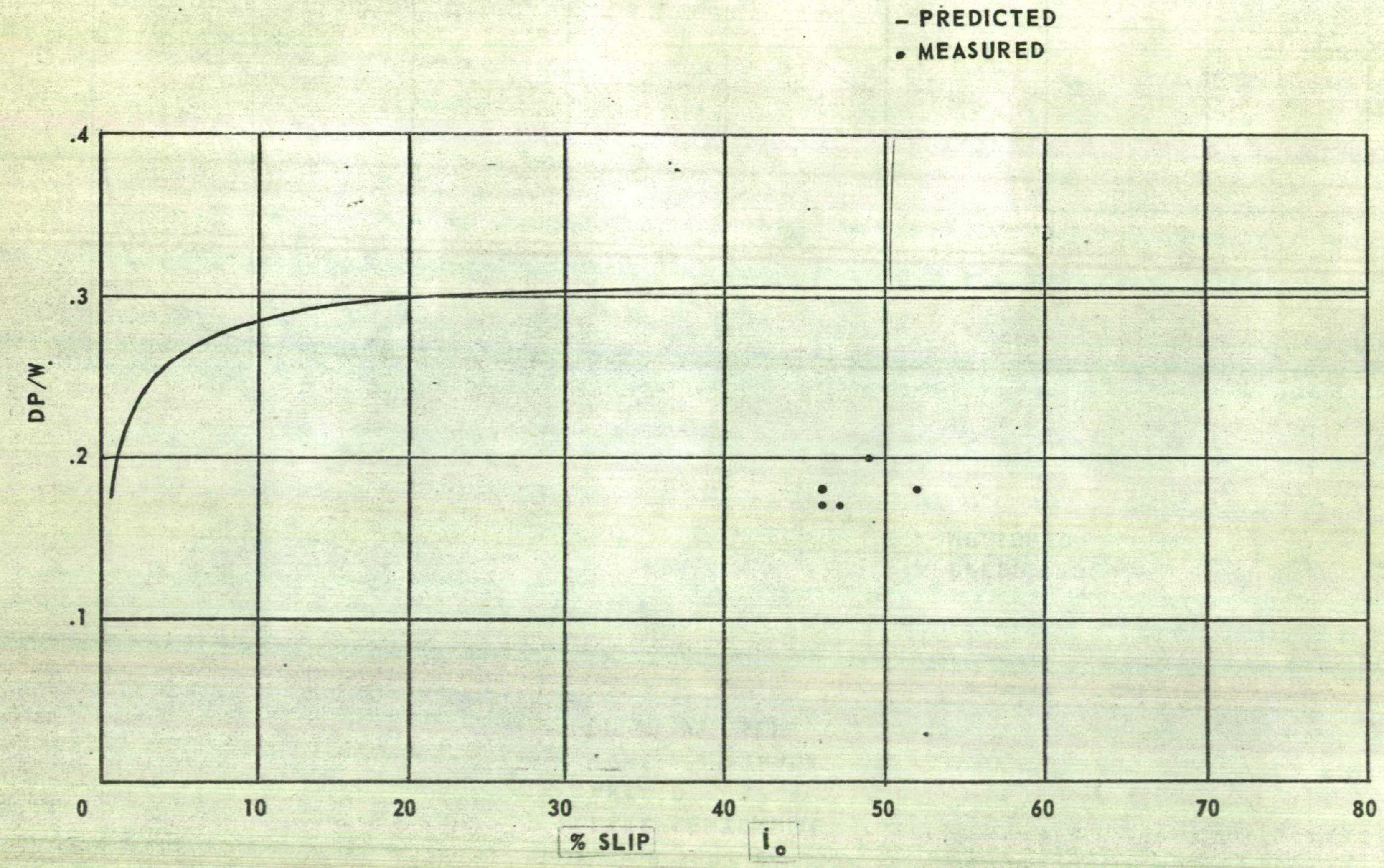


Fig. 13

18 SEPT 64
LAKE CENTENNIAL
AREA D
M 29 C 20" TRACK
DP / W VS. SLIP

TEST #190

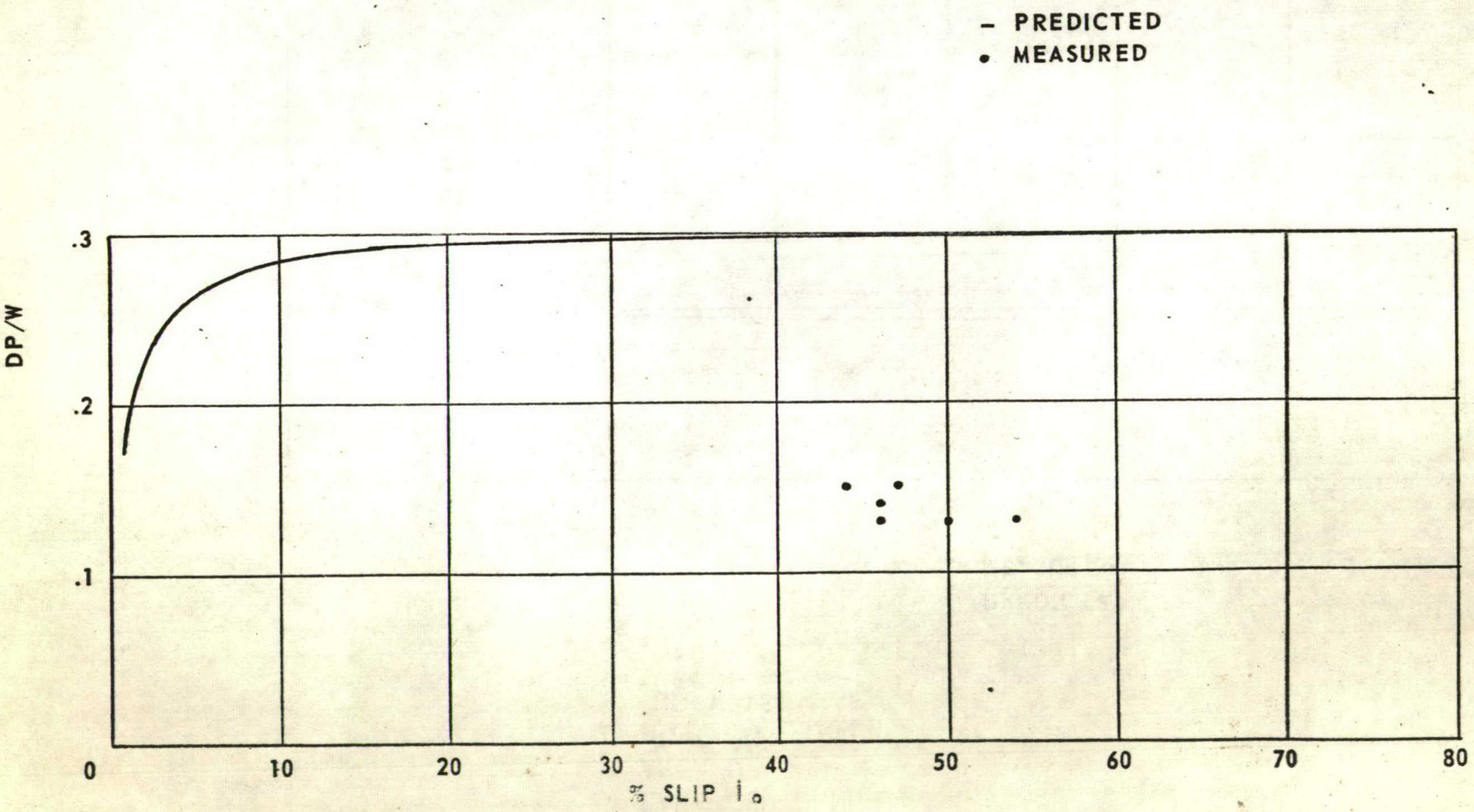


Fig. 14

23 SEPT 64
LAKE CENTENNIAL
AREA B - EAST
M 116
DP/W VS. SLIP

TESTS # 200E - 202E
208 E

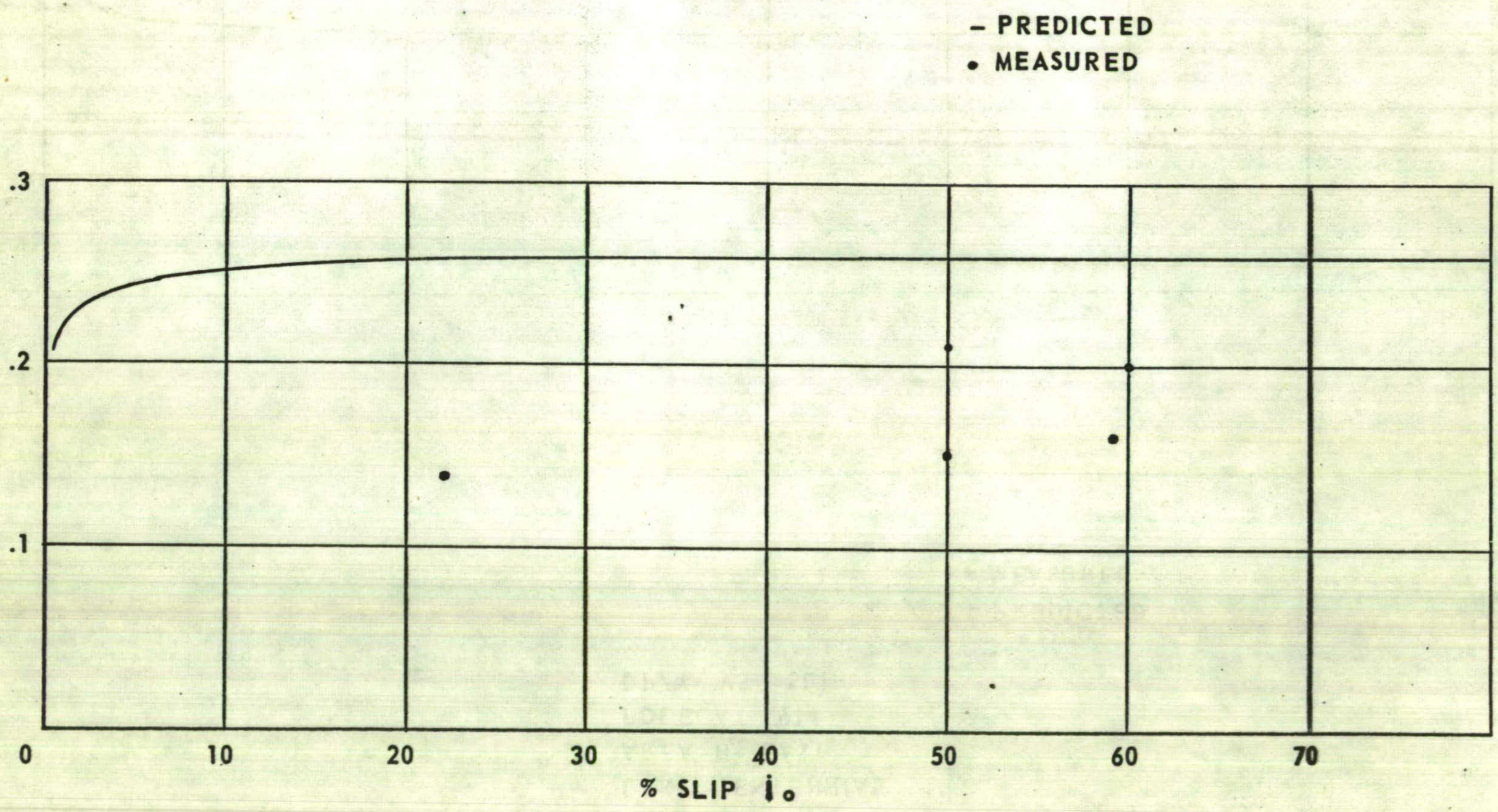


Fig. 15

23 SEPT 64 TEST # 207 A

LAKE CENTENNIAL

AREA B EAST

POLECAT 914

DP/W VS. SLIP

– PREDICTED

• MEASURED

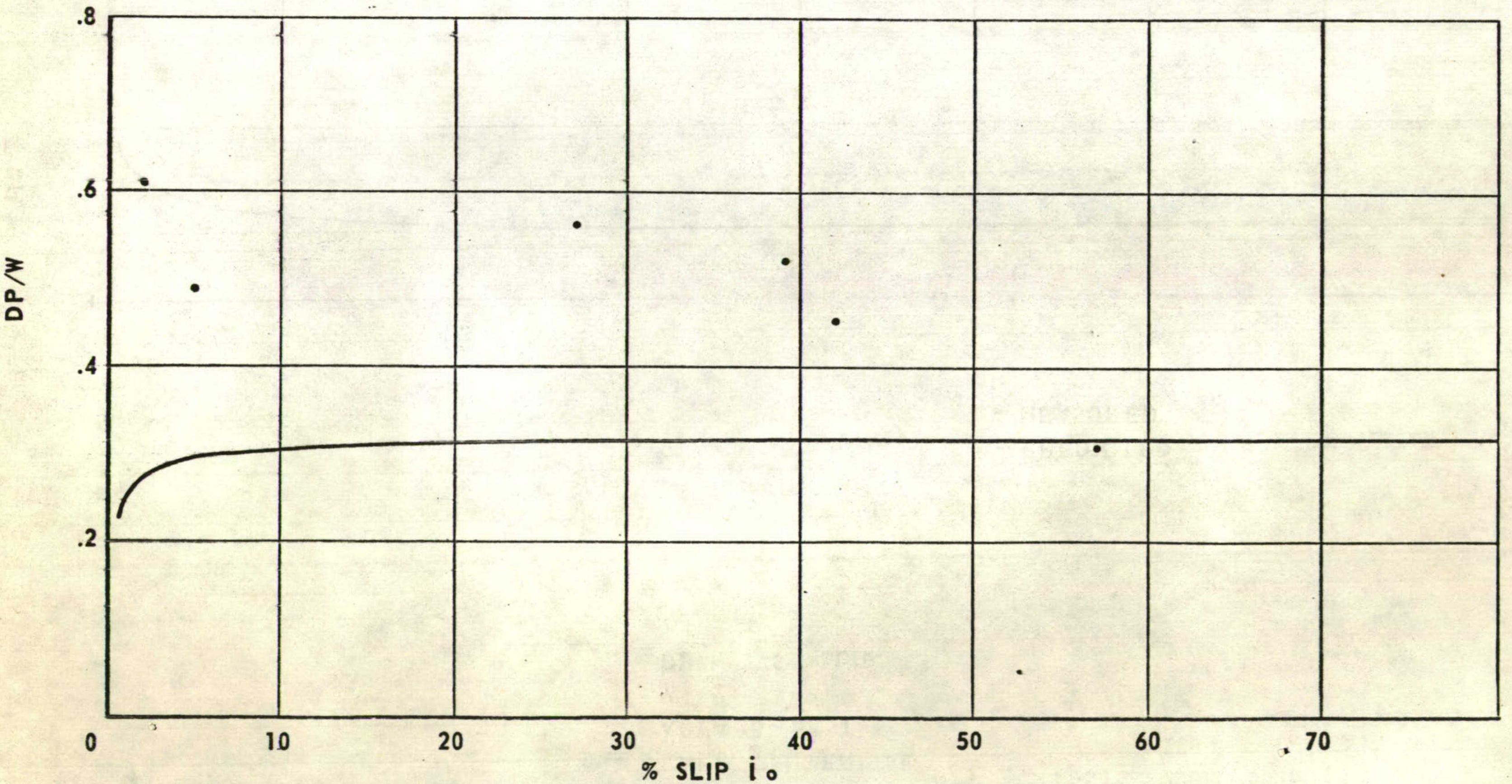
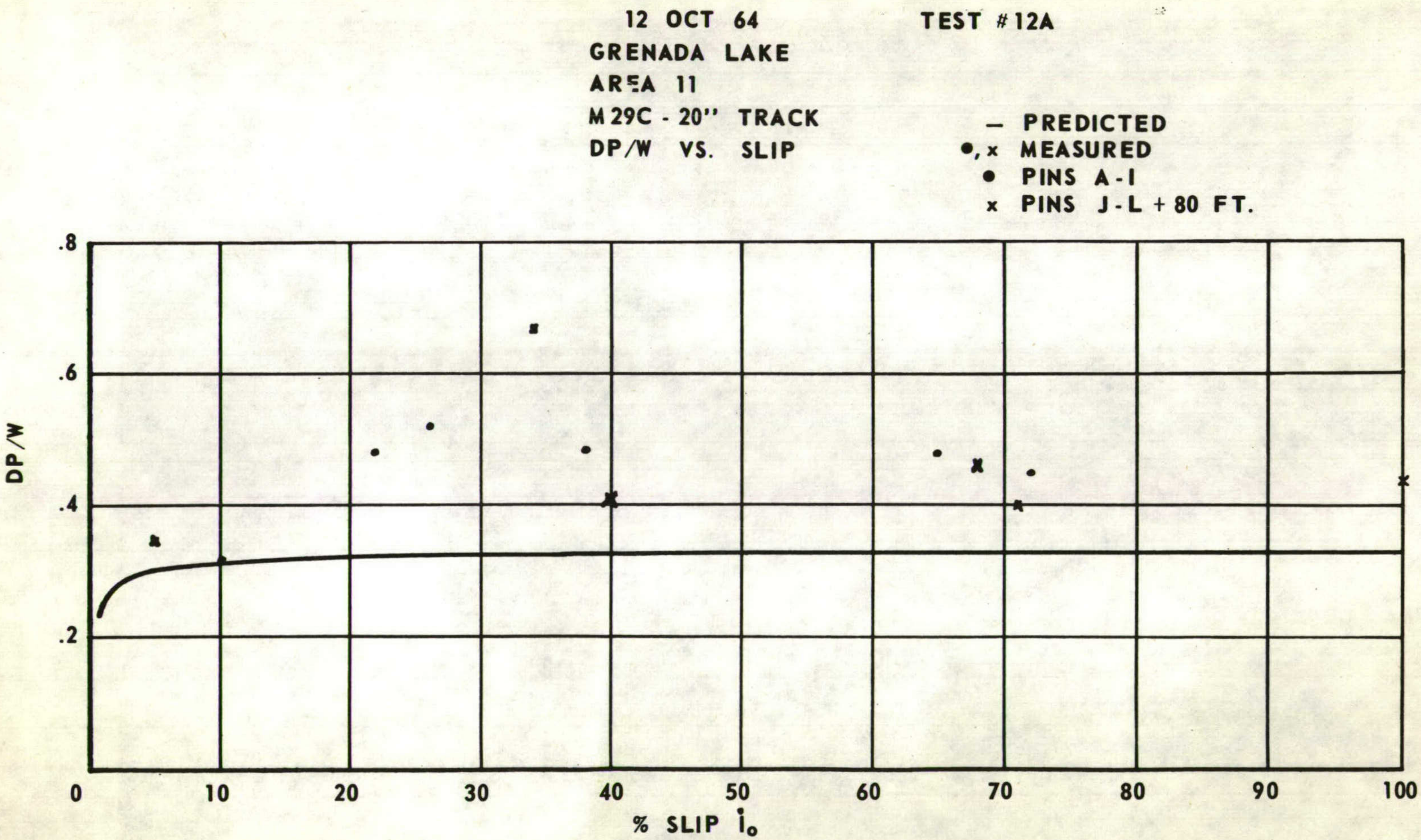


Fig. 16

Fig. 17 GRASS COVER ON TEST COURSE, LAKE CENTENNIAL, AREA B, VICKSBURG, SEPT, 1964.

Fig. 18 STUBBLE COVER ON TEST COURSE, LAKE CENTENNIAL, AREA F, VICKSBURG, SEPT, 1964.

Fig. 19 SELF-PROPELLED TEST, M56, LAKE CENTENNIAL, AREA B, VICKSBURG, SEPT, 1964.



12 OCT 64
TEST #12A
GRENADA LAKE
AREA 11
M 29C - 20'' TRACK
DP/W VS. SLIP
— PREDICTED
●, x MEASURED
● PINS A-I
x PINS J-L + 80 FT.
DP/W
.8
.6
.4
.2
0
10
20
30
40
50
60
70
80
90
100
% SLIP $\dot{i}_o$

Fig. 20

15 OCT 64 TEST #18C
GRENADA LAKE
AREA 11
M29C - 20" TRACK
DP/W VS. SLIP

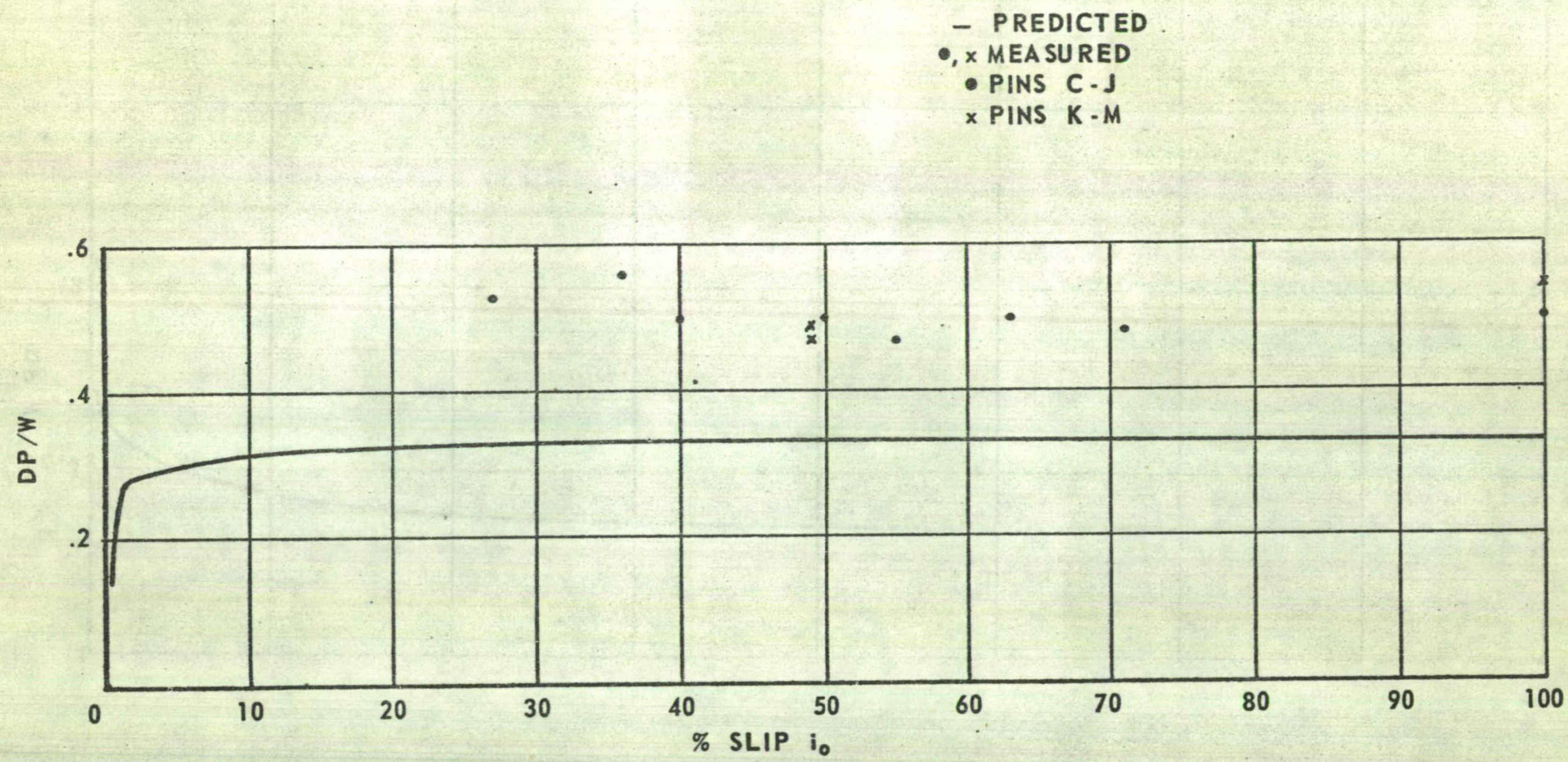


Fig. 21

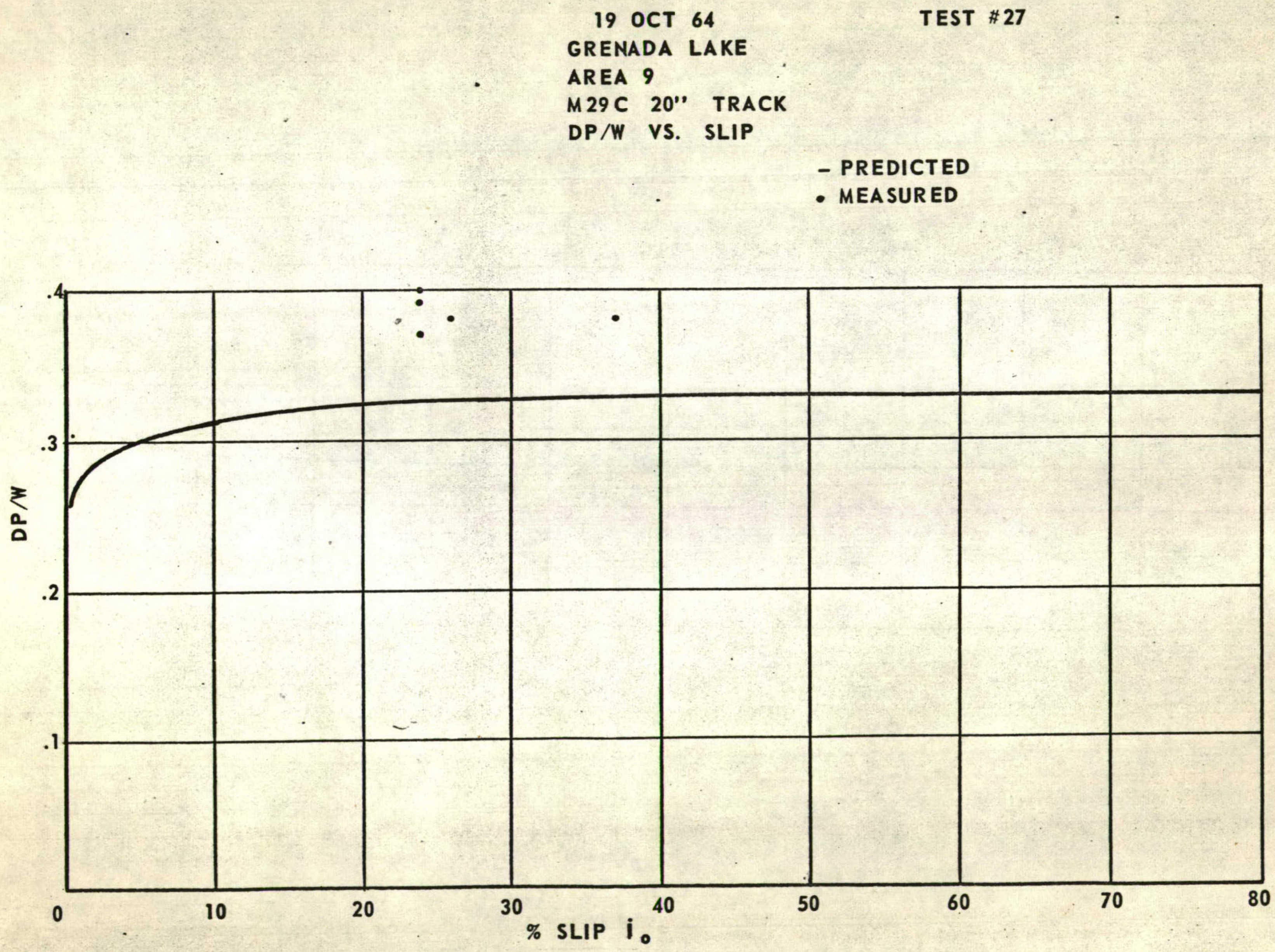

19 OCT 64
GRENADA LAKE
AREA 9
M29C 20" TRACK
DP/W VS. SLIP
TEST #27
- PREDICTED
• MEASURED
DP/W
.4
.3
.2
.1
0
10
20
30
40
50
60
70
80
% SLIP i_o

Fig. 22

21 OCT 64 TEST #32

GRENADA LAKE

AREA 9

M29C 12" TRACK

DP/W VS. SLIP

– PREDICTED

•, o, x MEASURED

• PINS A-G

o PINS H-I

x PINS J-K

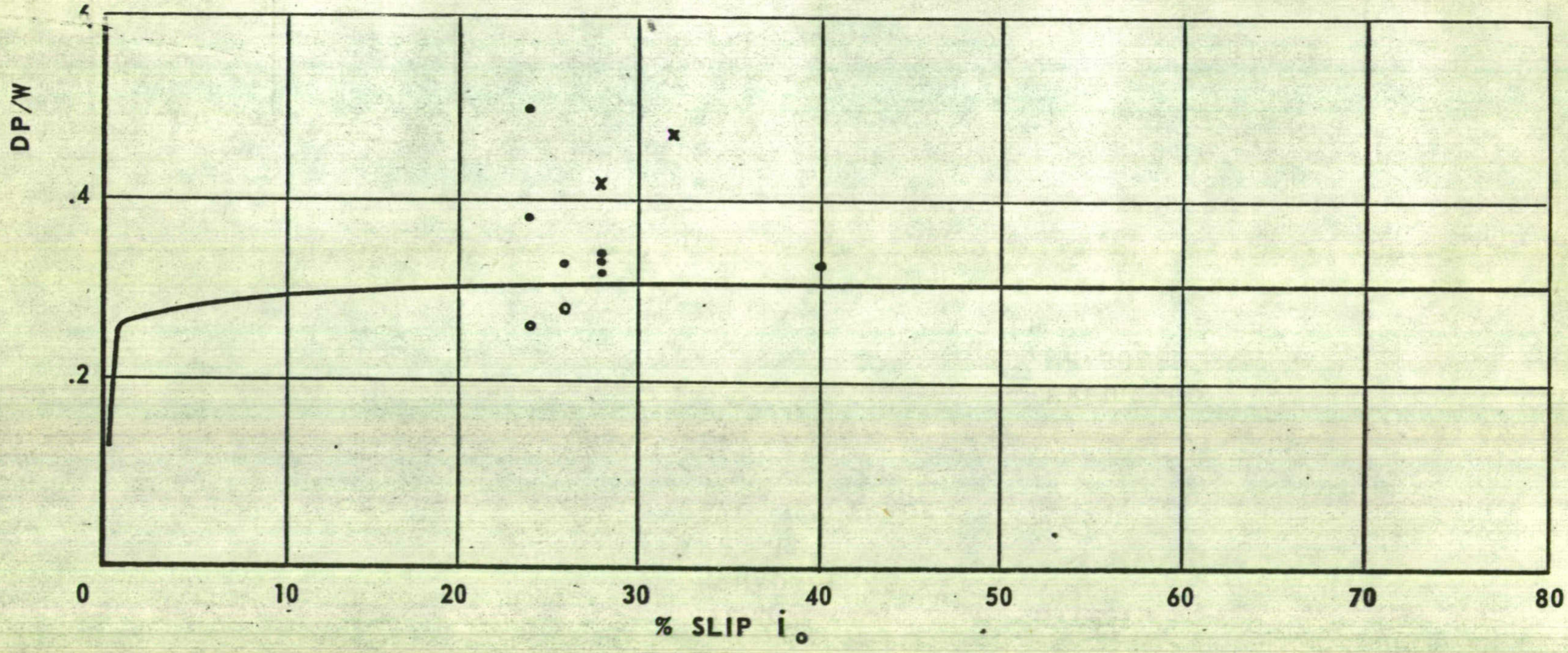


FIG. 23

22 OCT 64 TEST #34
GRENADA LAKE
AREA 12
M29C 12" TRACK
DP/W VS. SLIP

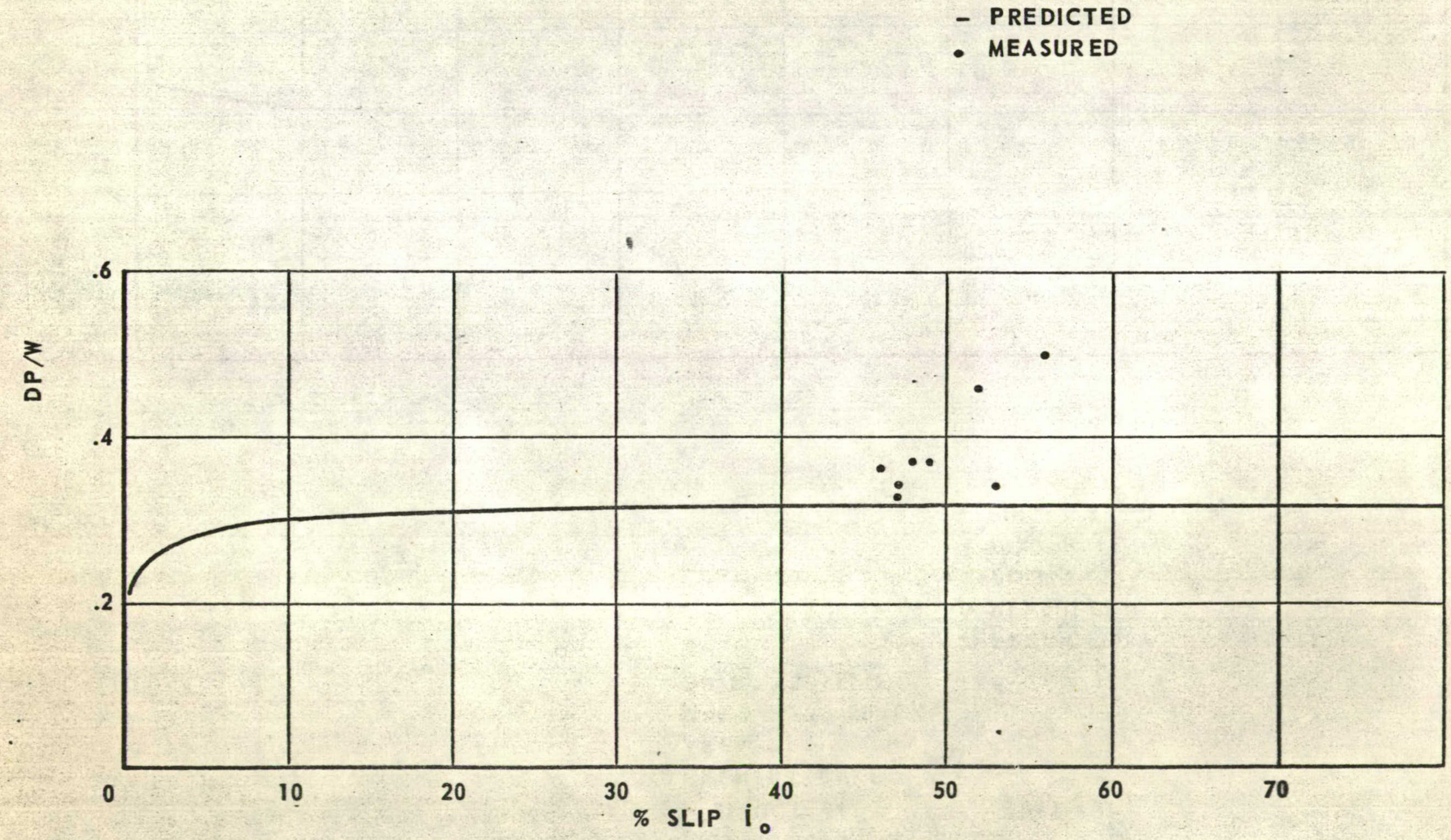


Fig. 24

21 OCT 64 TEST # 35

GRENADA LAKE

AREA 12

M29C 20" TRACK

DP/W VS. SLIP

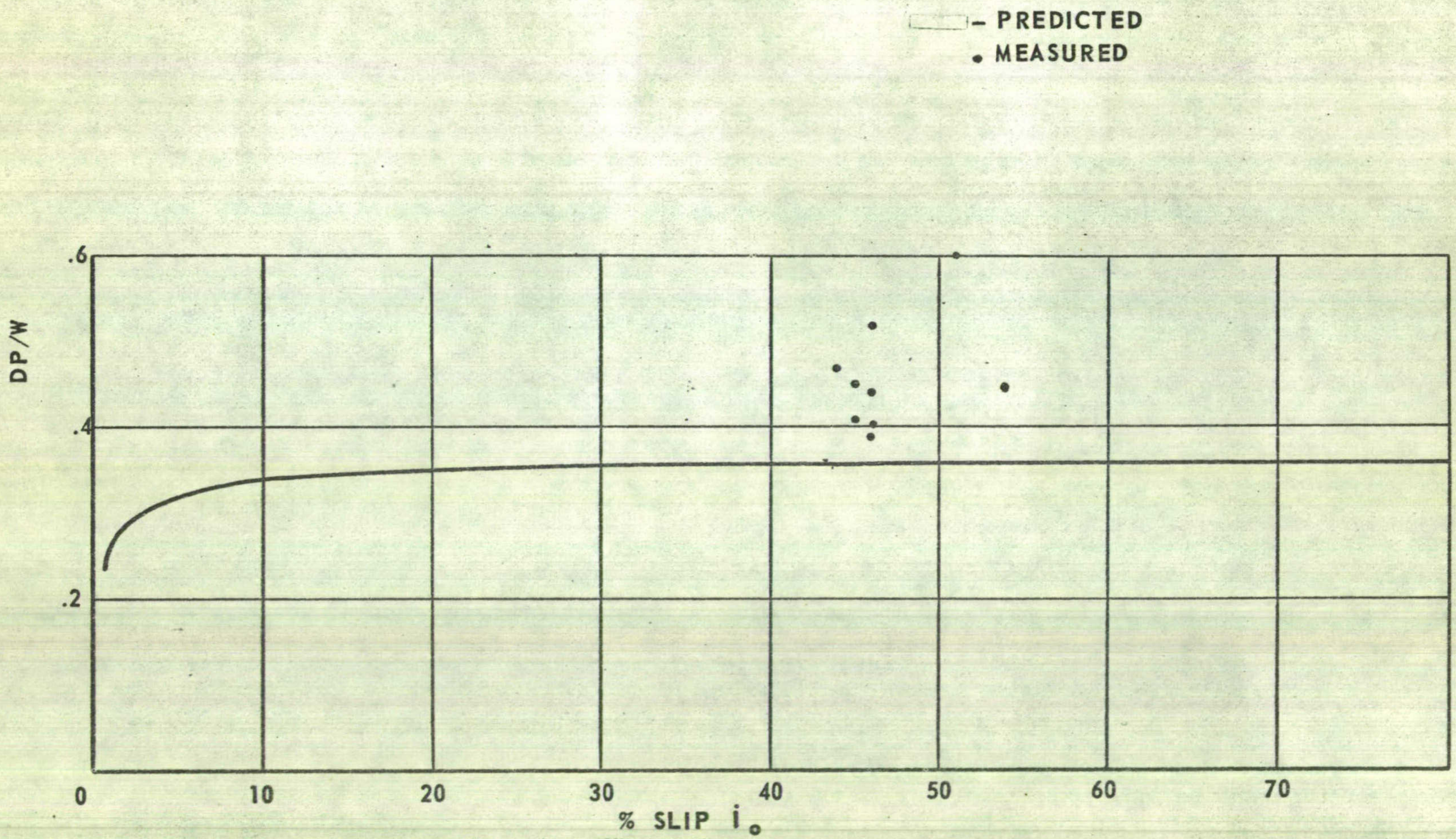


Fig. 25

21 OCT 64 TEST #30
GRENADA LAKE
AREA 9
POLECAT 914
DP/W VS. SLIP

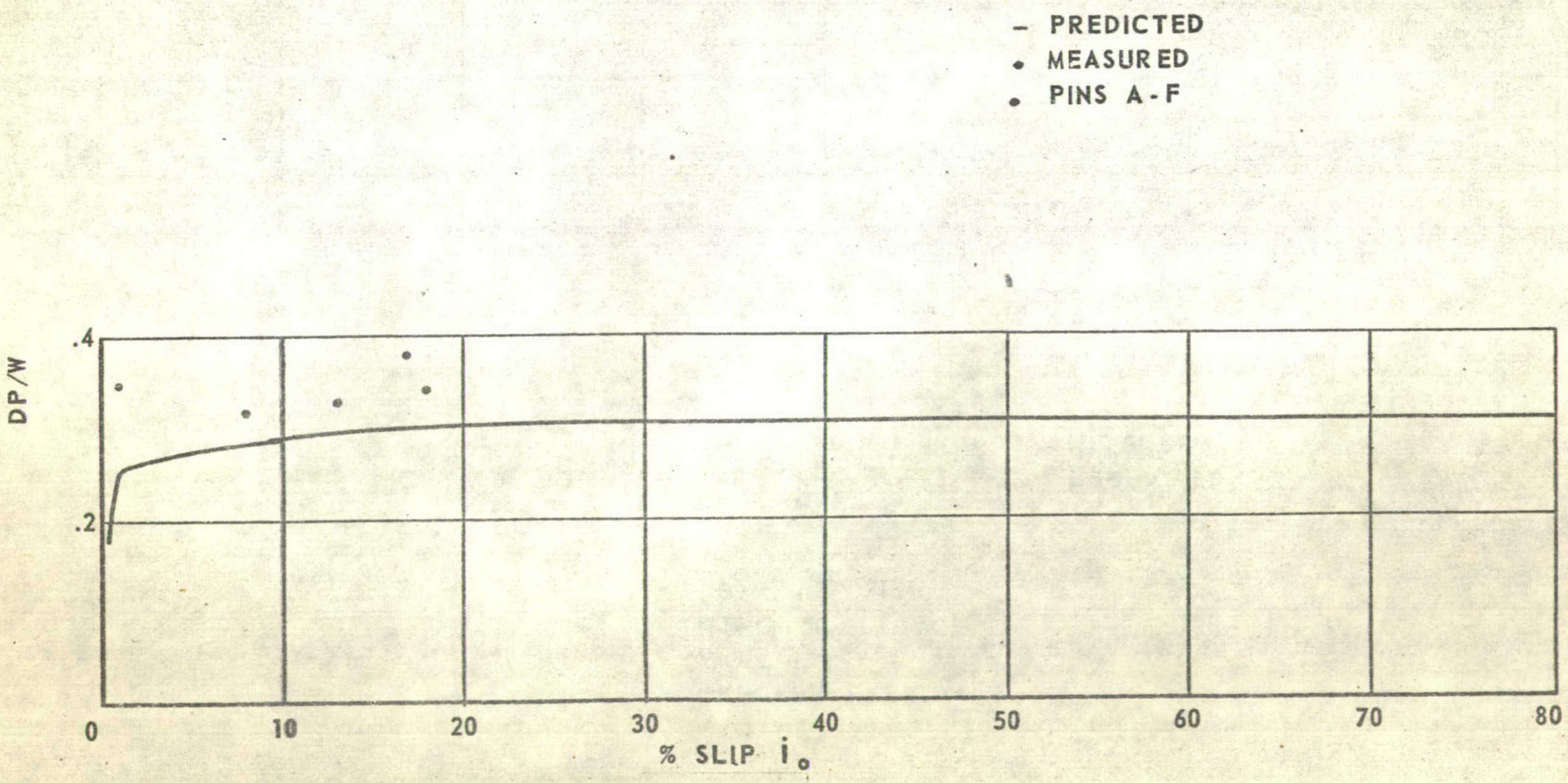


Fig. 26

21 OCT 64 TEST #30

GRENADA LAKE

AREA 9

POLECAT 914

DP/W VS. SLIP

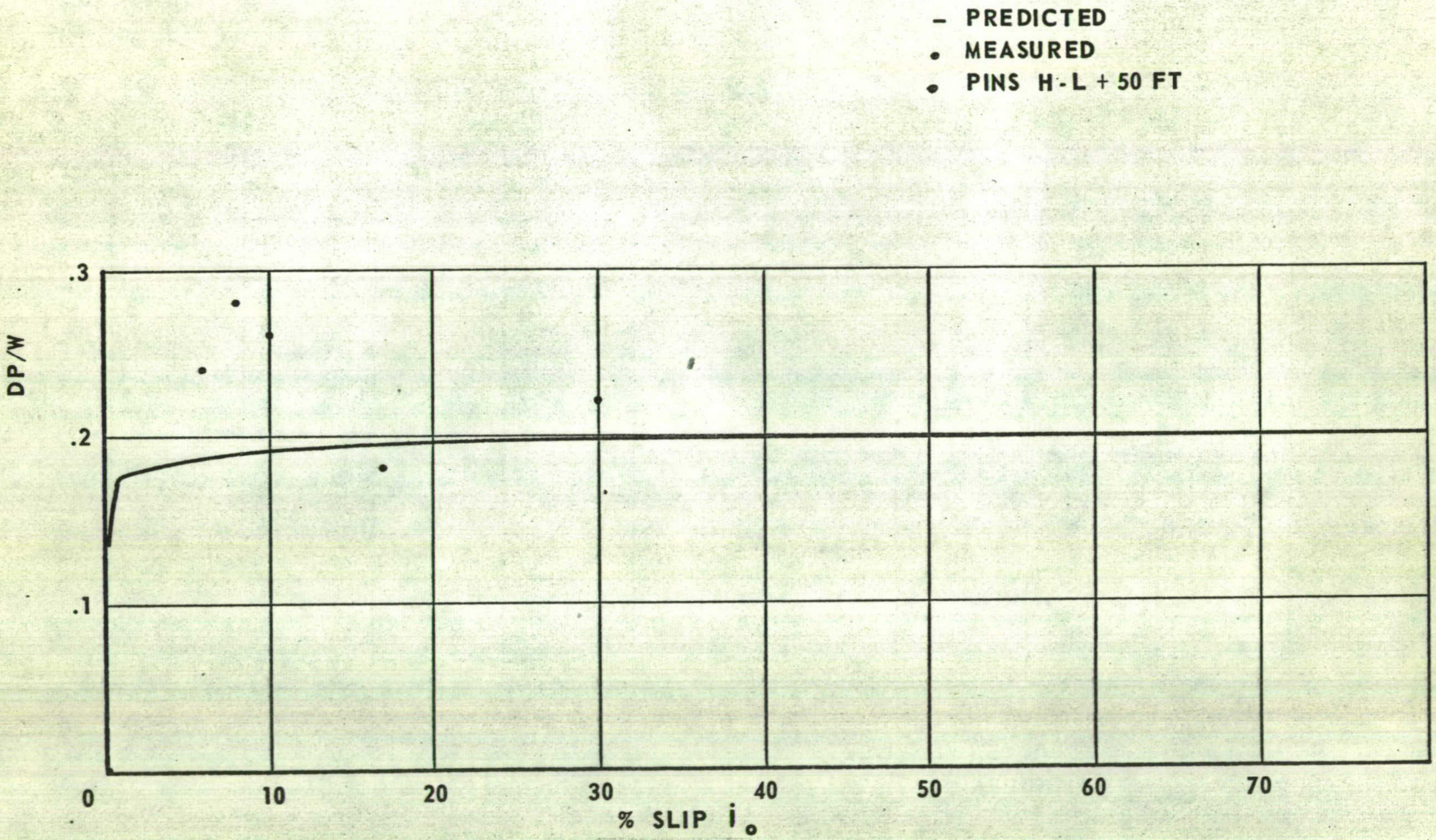


Fig. 27

26 OCT 64
GRENADA LAKE
AREA 12
POLECAT 914
DP/W VS. SLIP

TEST # 47 (2ND RUN)

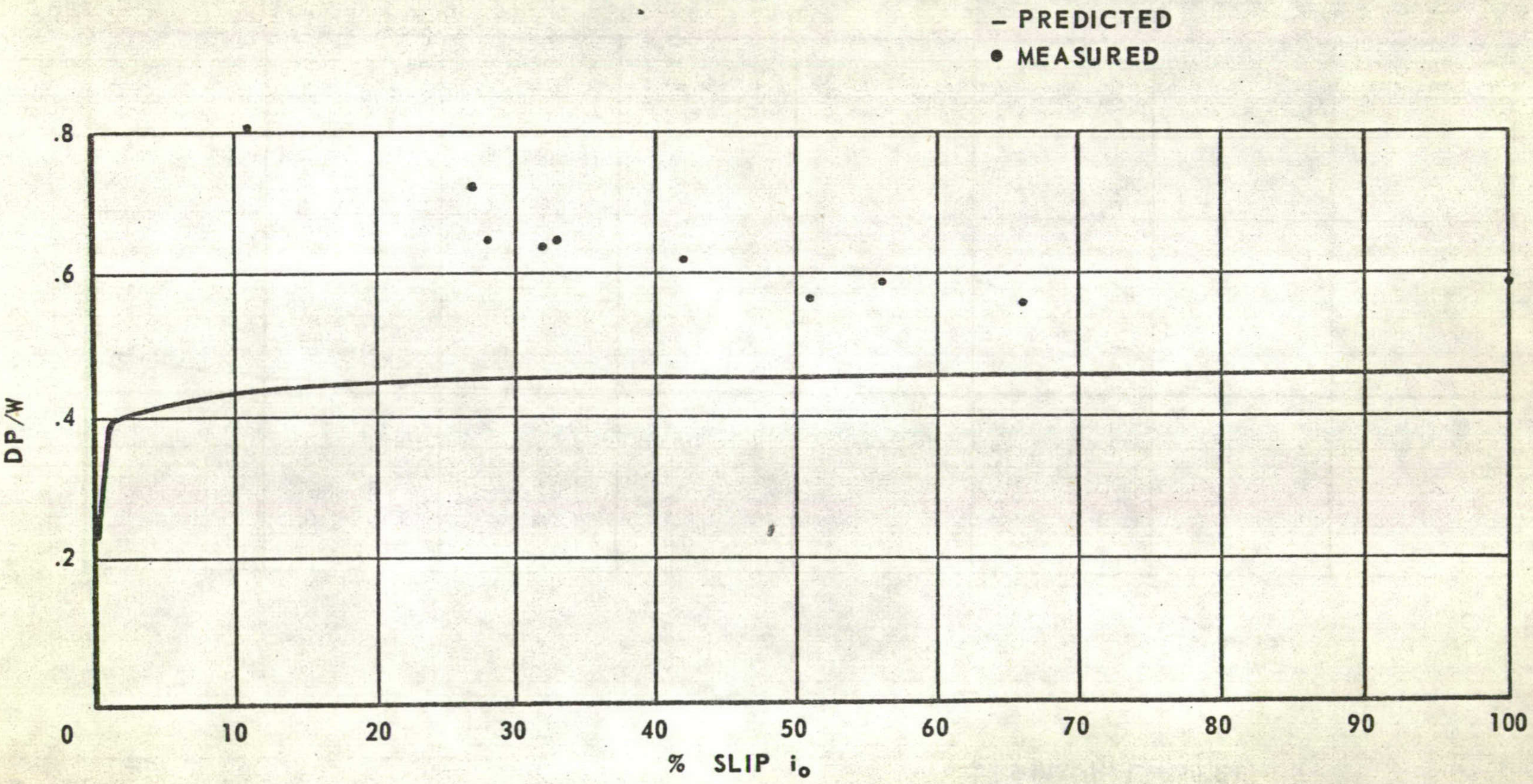


Fig. 28

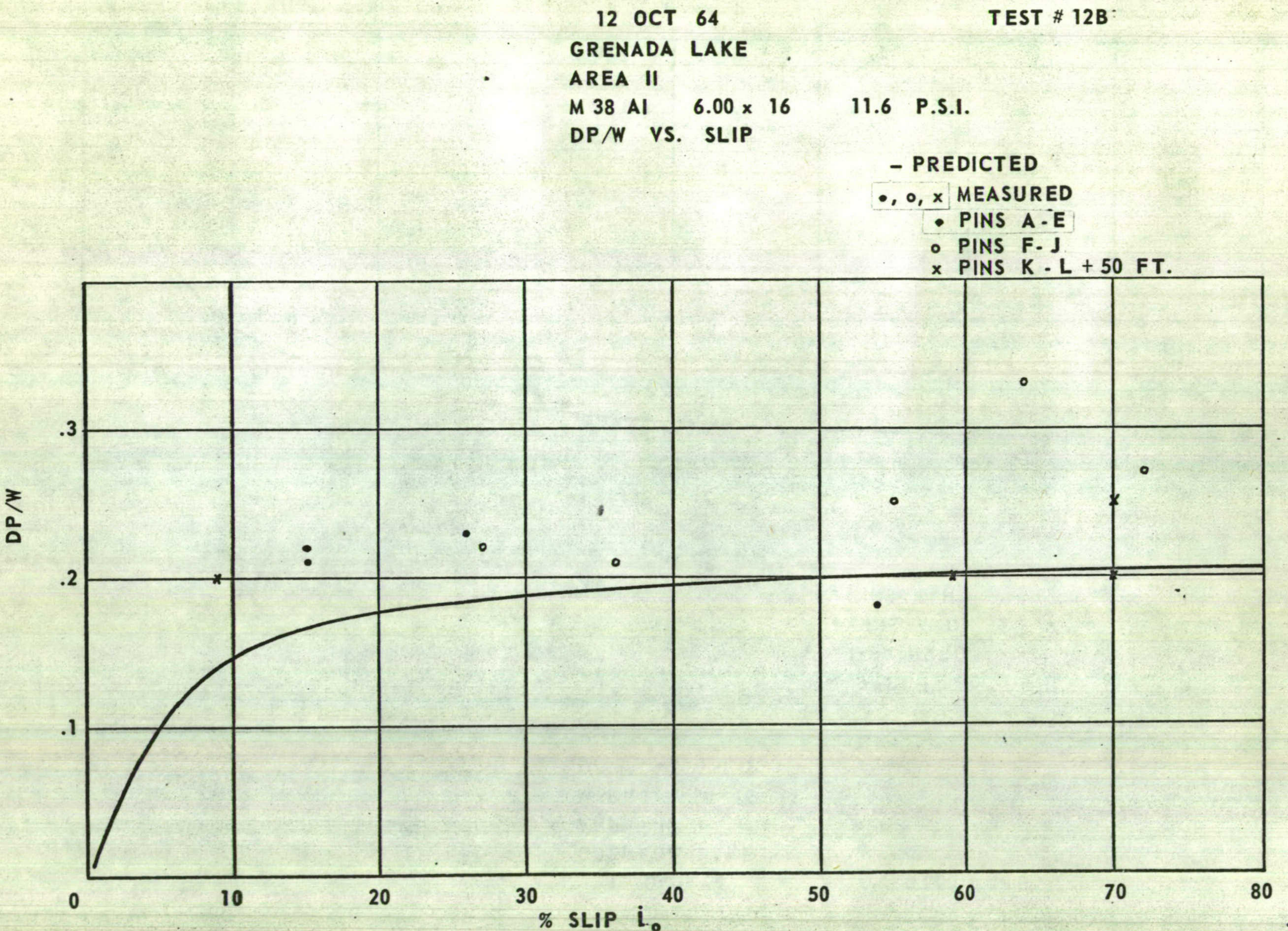

12 OCT 64
TEST # 12B
GRENADA LAKE
AREA II
M 38 AI 6.00 x 16 11.6 P.S.I.
DP/W VS. SLIP
– PREDICTED
•, o, x MEASURED
• PINS A - E
o PINS F - J
x PINS K - L + 50 FT.
.3
.2
.1
DP/W
0
10
20
30
40
50
60
70
80
% SLIP i_o

Fig. 29

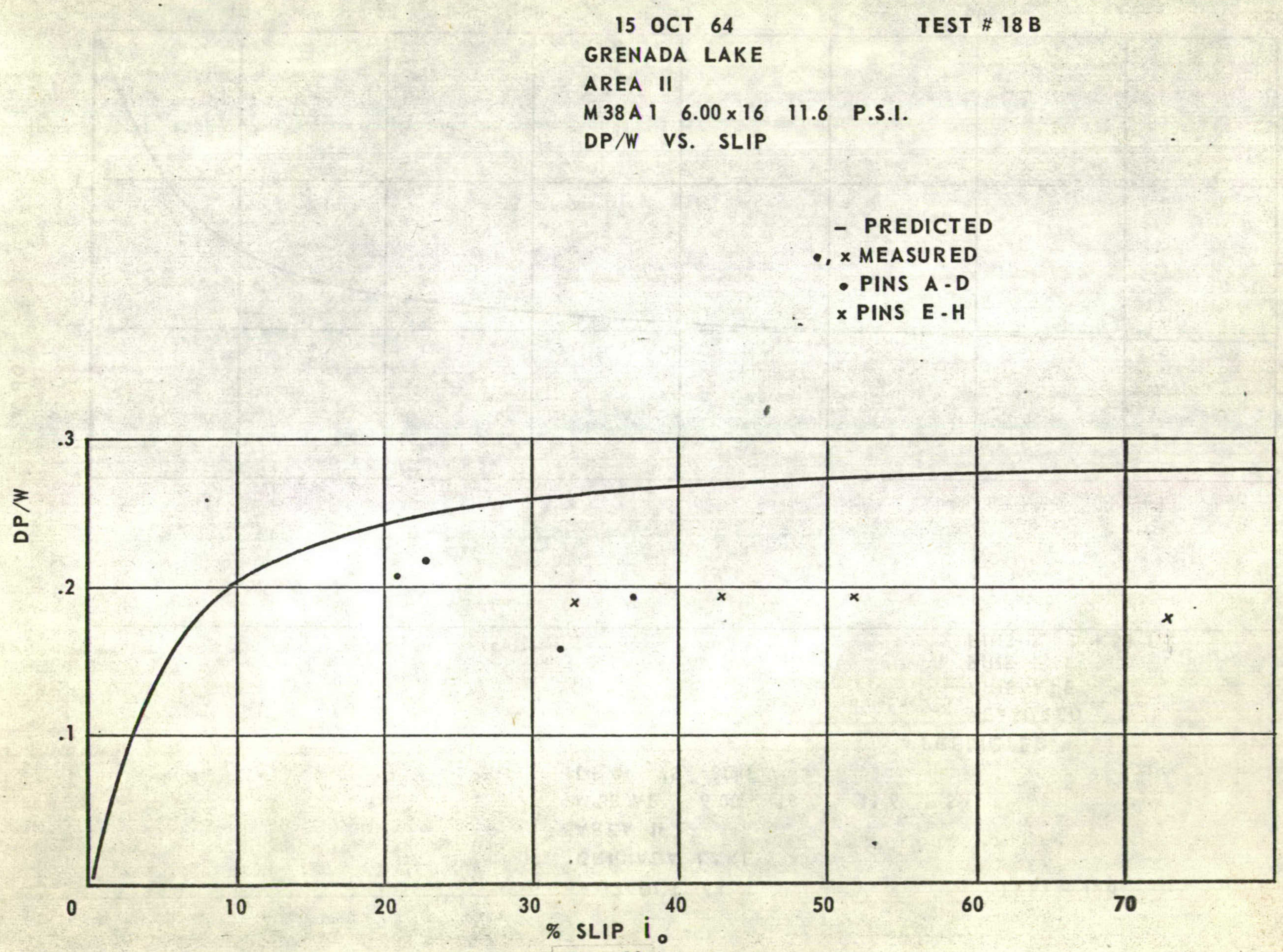

15 OCT 64
TEST # 18 B
GRENADA LAKE
AREA II
M38A1 6.00 x 16 11.6 P.S.I.
DP/W VS. SLIP
– PREDICTED
•, x MEASURED
• PINS A-D
x PINS E-H
DP/W
.3
.2
.1
0
10
20
30
40
50
60
70
% SLIP i_o

Fig. 30

12 OCT 64 TEST # 12C
GRENADA LAKE
AREA 11
M 37 9.00 x 16 30 P.S.I.
DP/W VS. SLIP

— PREDICTED
●, x MEASURED
● PINS A-H
x PINS J-L + 50 FT.

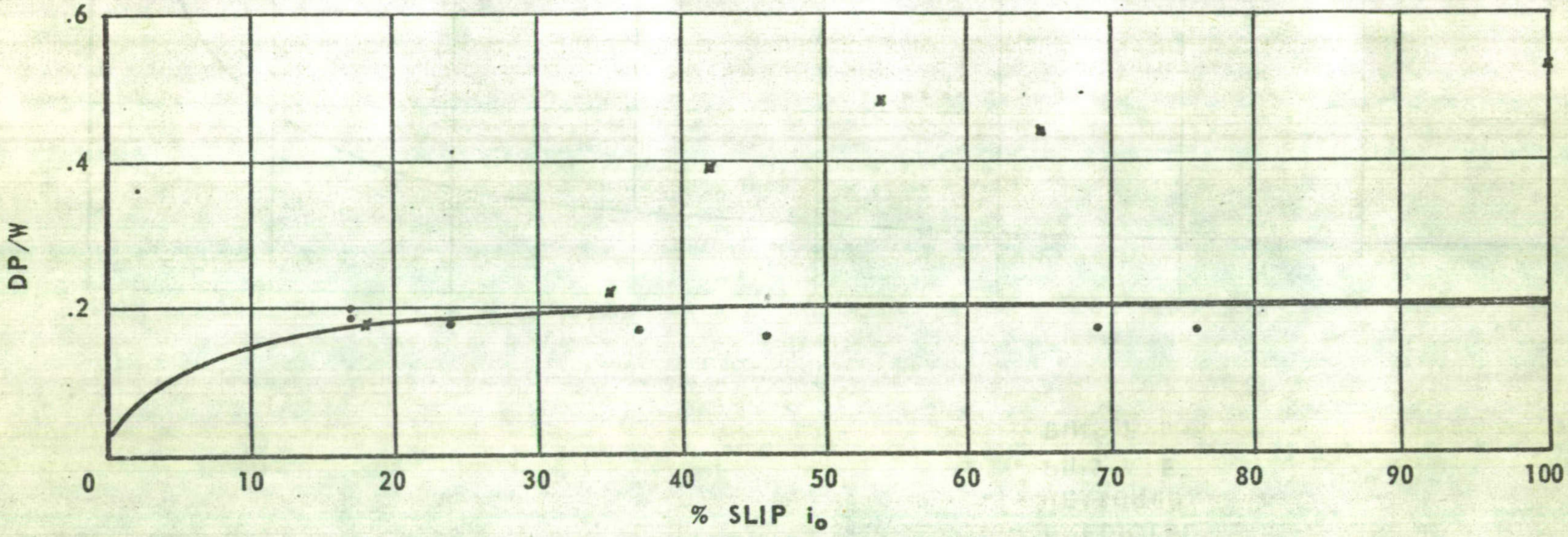


Fig. 31

13 OCT 64 TEST # 15

GRENADA LAKE

AREA 9

M37 9.00 x 16 6.5 P.S.I.

DP/W VS. SLIP

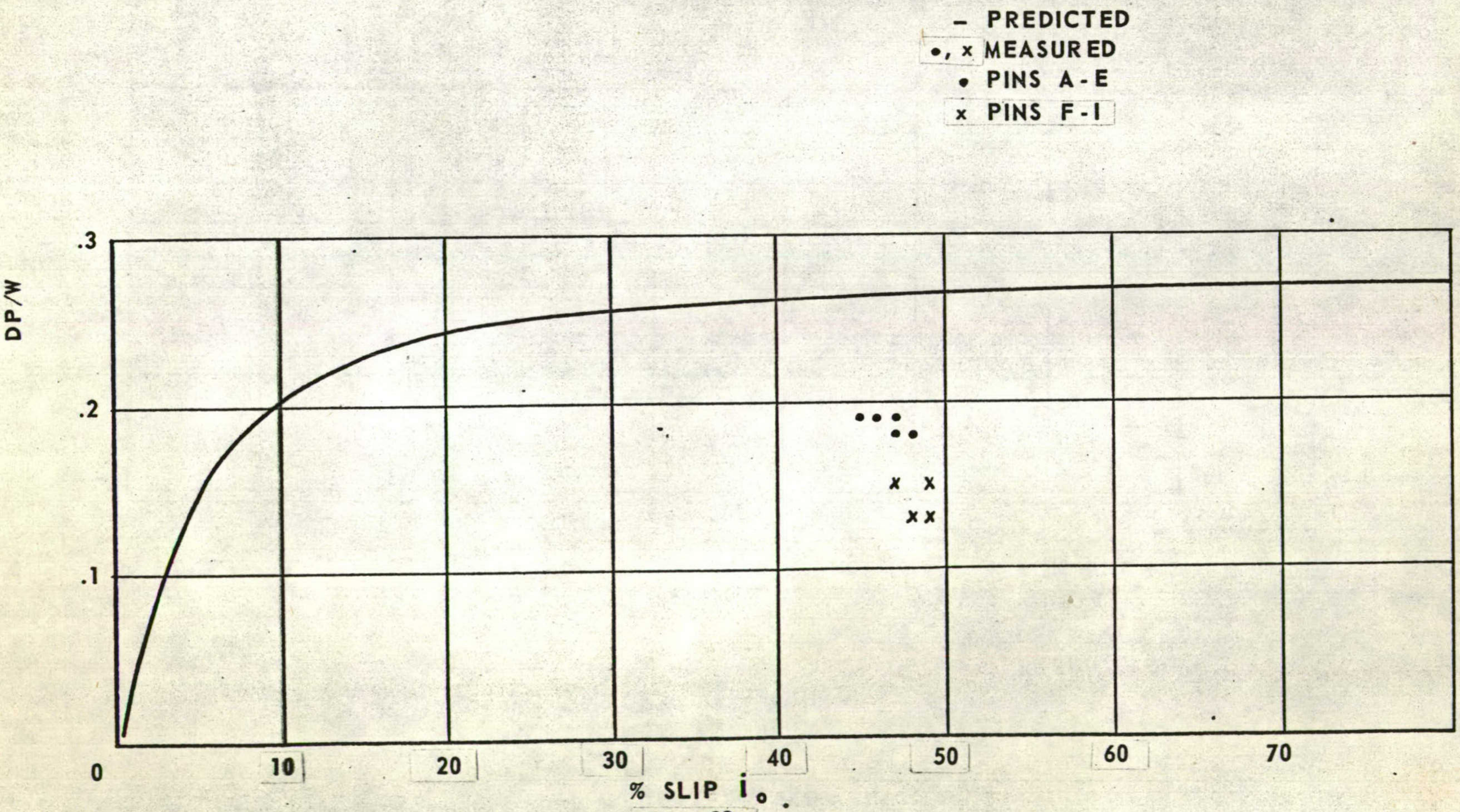


Fig. 32

15 OCT 64 TEST # 18A

GRENADA LAKE

AREA II

M 37 9.00 x 16 30 P.S.I.

DP/W VS. SLIP

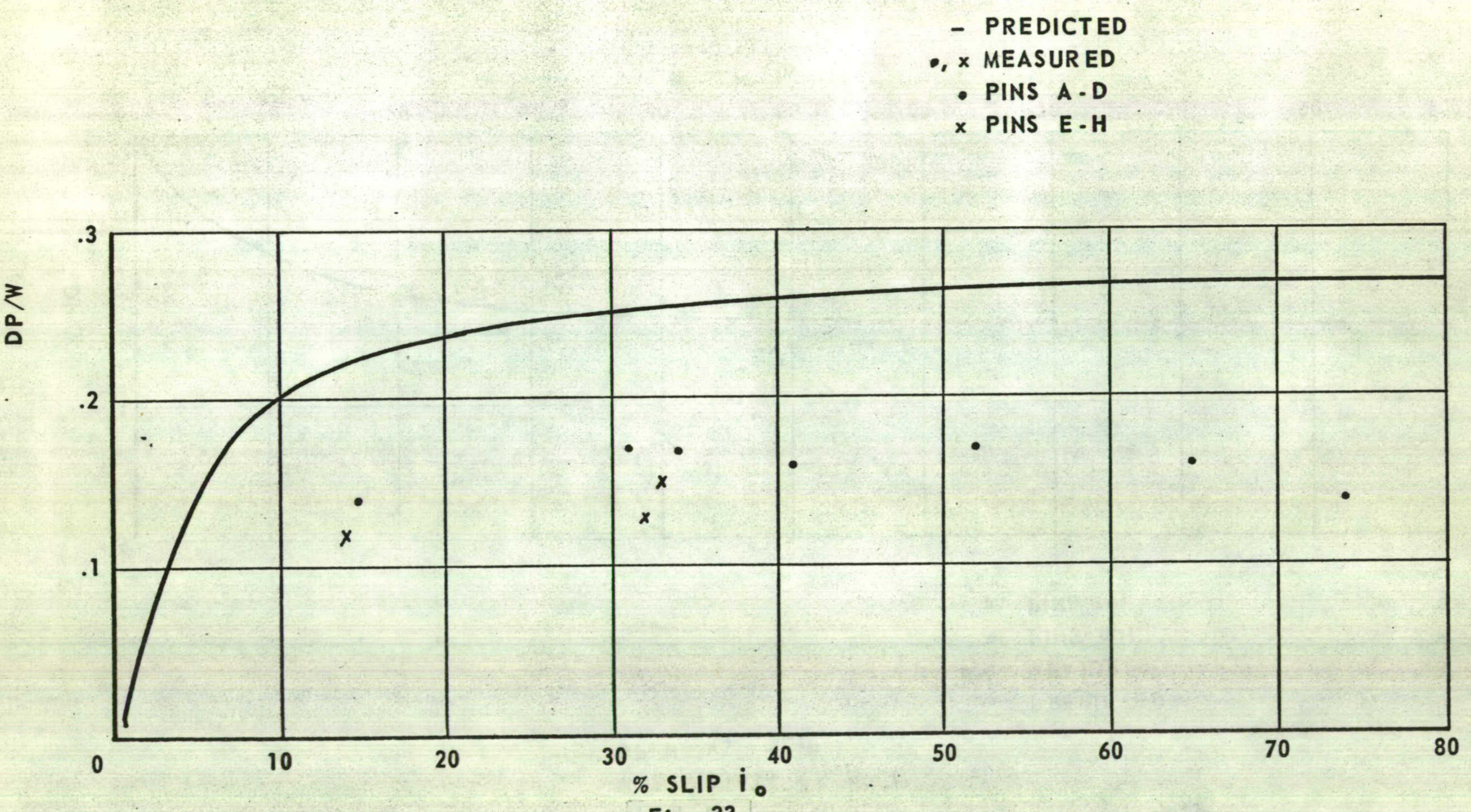


Fig. 33

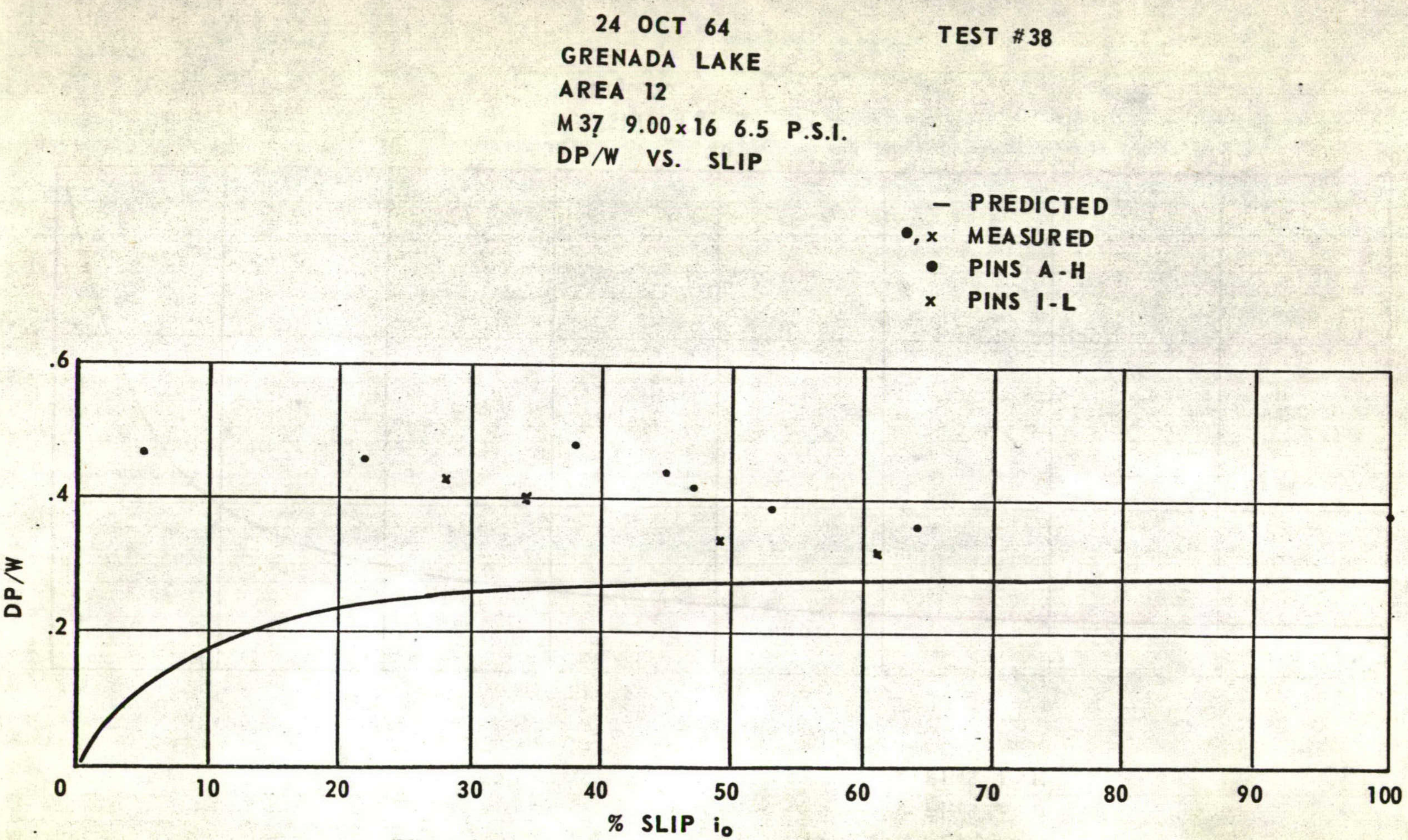

24 OCT 64
GRENADA LAKE
AREA 12
M37 9.00x16 6.5 P.S.I.
DP/W VS. SLIP
TEST #38
— PREDICTED
●, x MEASURED
● PINS A-H
x PINS I-L
DP/W
.6
.4
.2
0
10
20
30
40
50
60
70
80
90
100
% SLIP i_o

Fig. 34

27 OCT 64 TEST # 48

GRENADA LAKE

AREA 12

M 37 9.00 x 16 30 P.S.I.

DP/W VS. SLIP

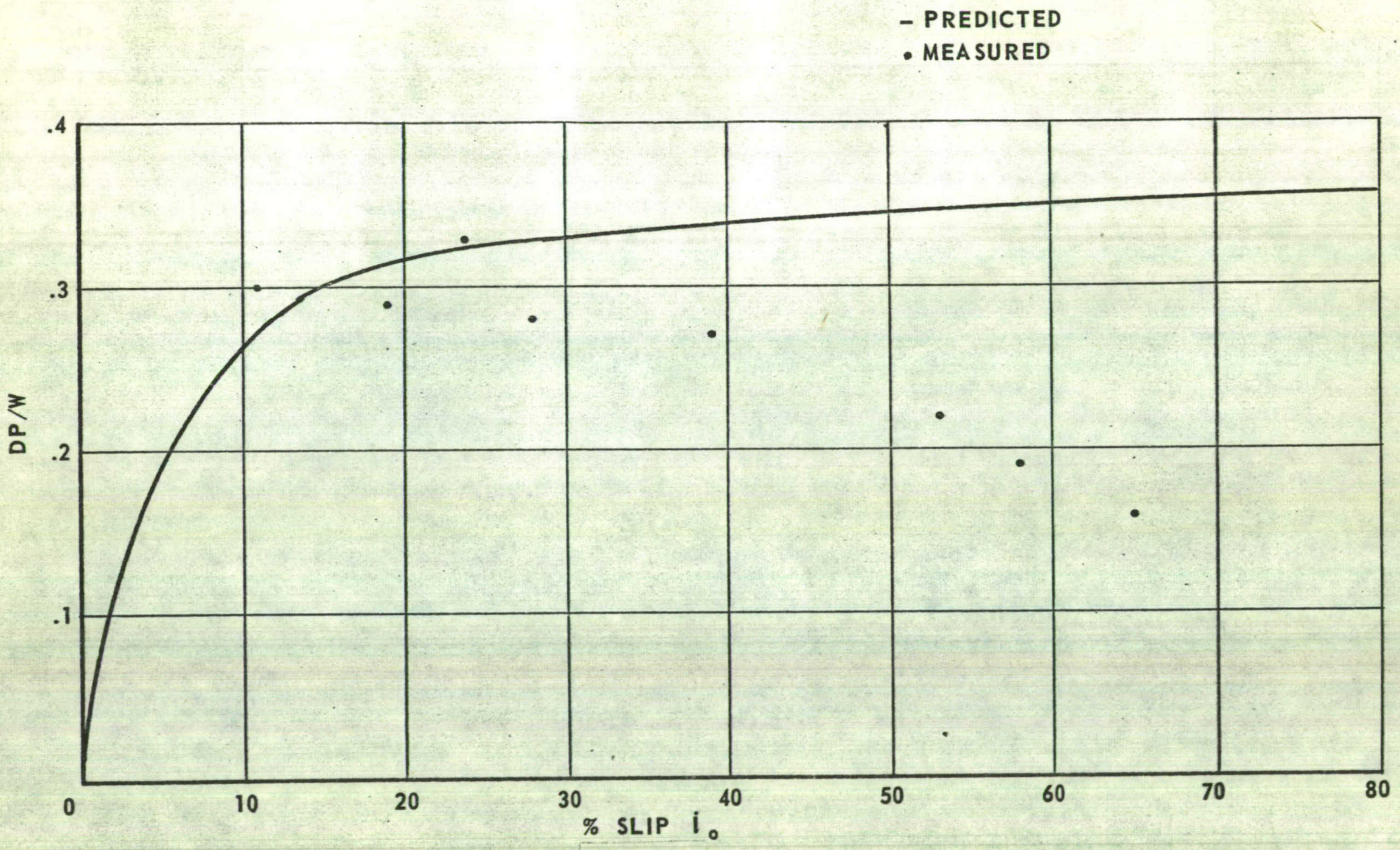


Fig. 35

19 OCT 64 TEST #26

GRENADA LAKE

AREA 9

M35A1 11.00x20 13.0 P.S.I.

DP/W VS. SLIP

– PREDICTED

•, x MEASURED

• PINS A-D

x PINS E-G

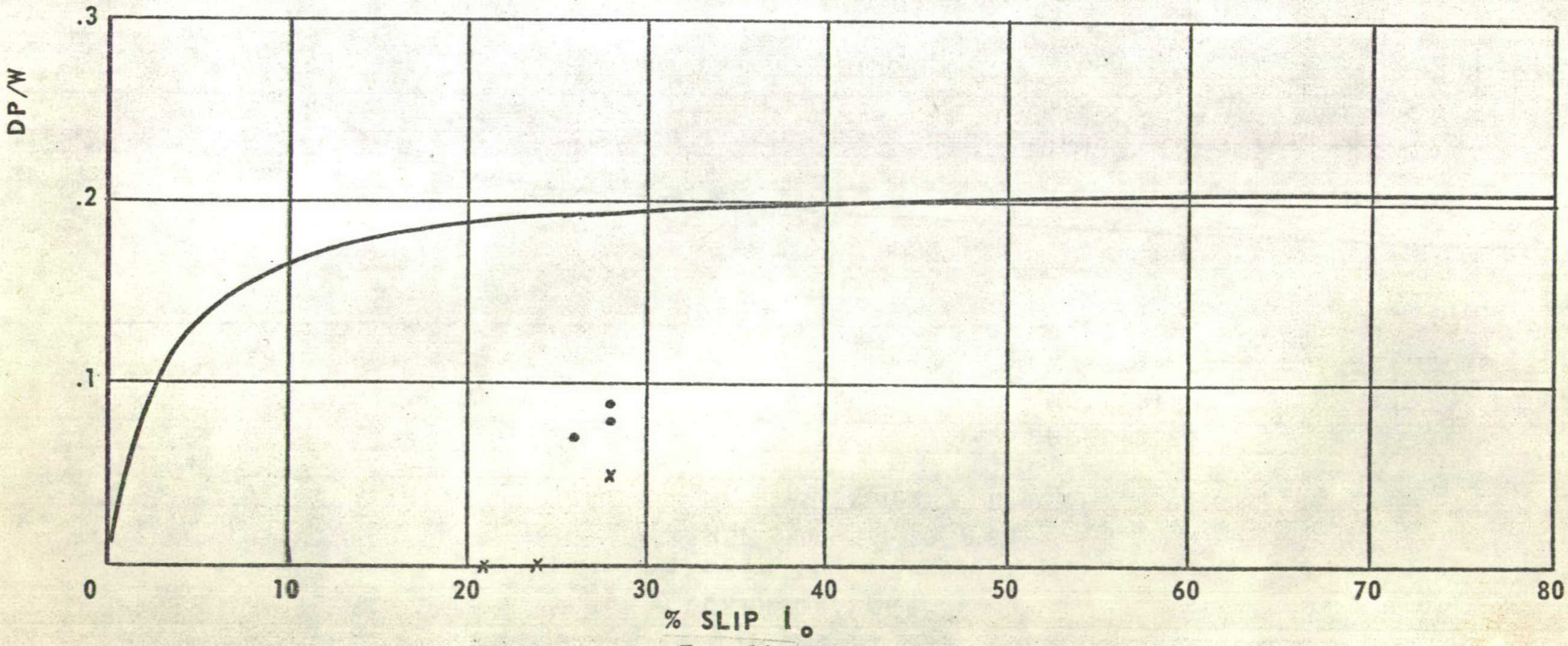


Fig. 36

25 OCT 64
GRENADA LAKE
AREA 12
M35A1 · 11.00×20 13 PSI
DP/ VS. SLIP

TEST #43

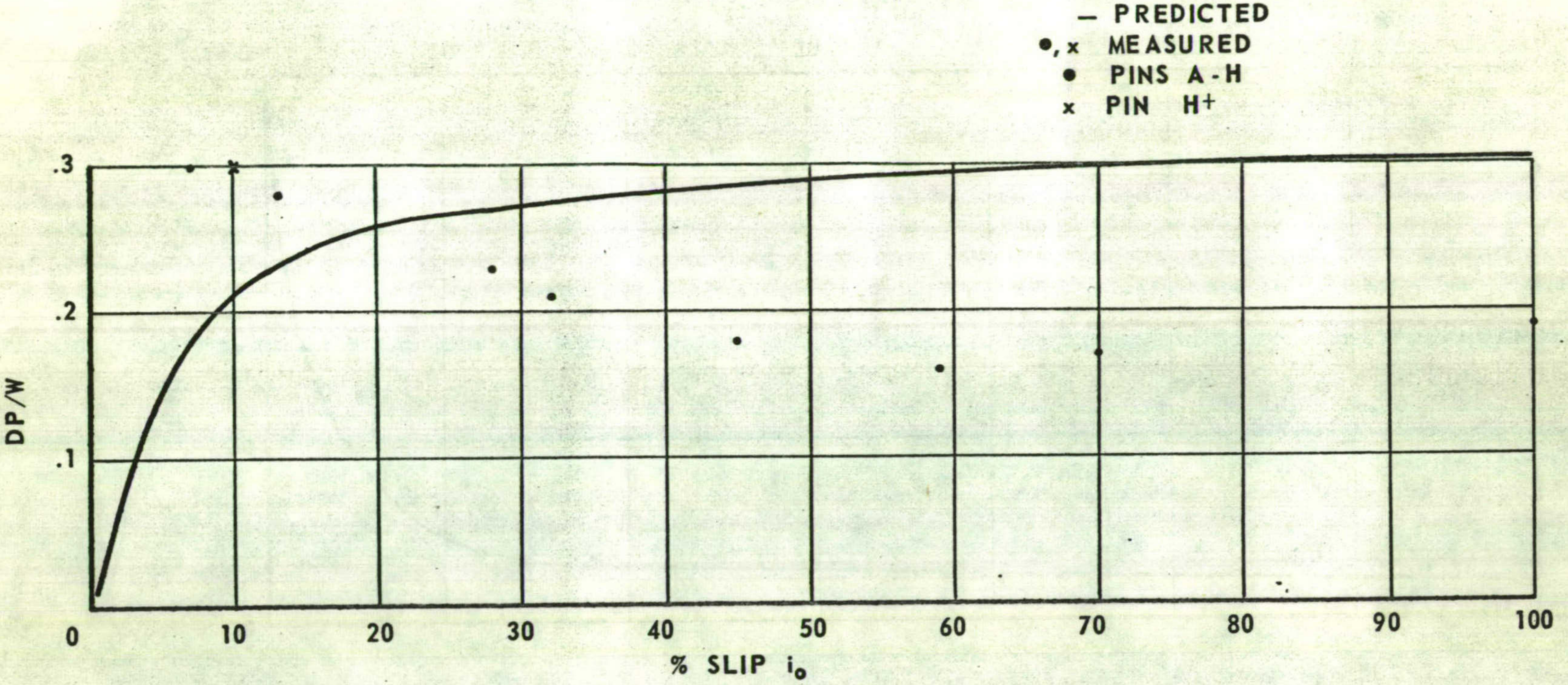


Fig. 37

14 AUG 1964
G.M. PROVING GROUNDS – SAND COURSE
MILFORD, MICHIGAN
EUCLID C-6 CRAWLER TRACTOR
DRAWBAR LOAD VS. SLIP

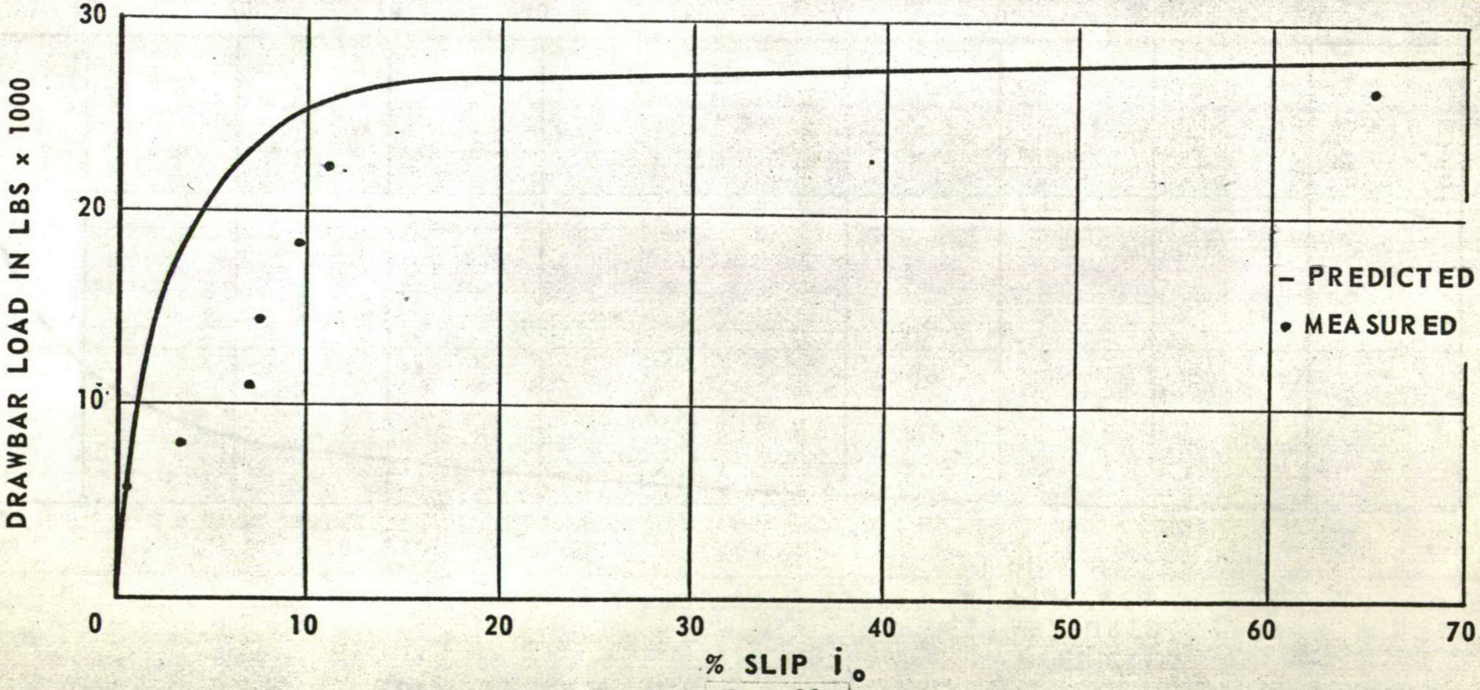


Fig. 38

18 AUG 1964
G.M. PROVING GROUNDS – CLAY COURSE
MILFORD, . MICHIGAN
EUCLID C-6 CRAWLER TRACTOR
DRAWBAR LOAD VS. SLIP

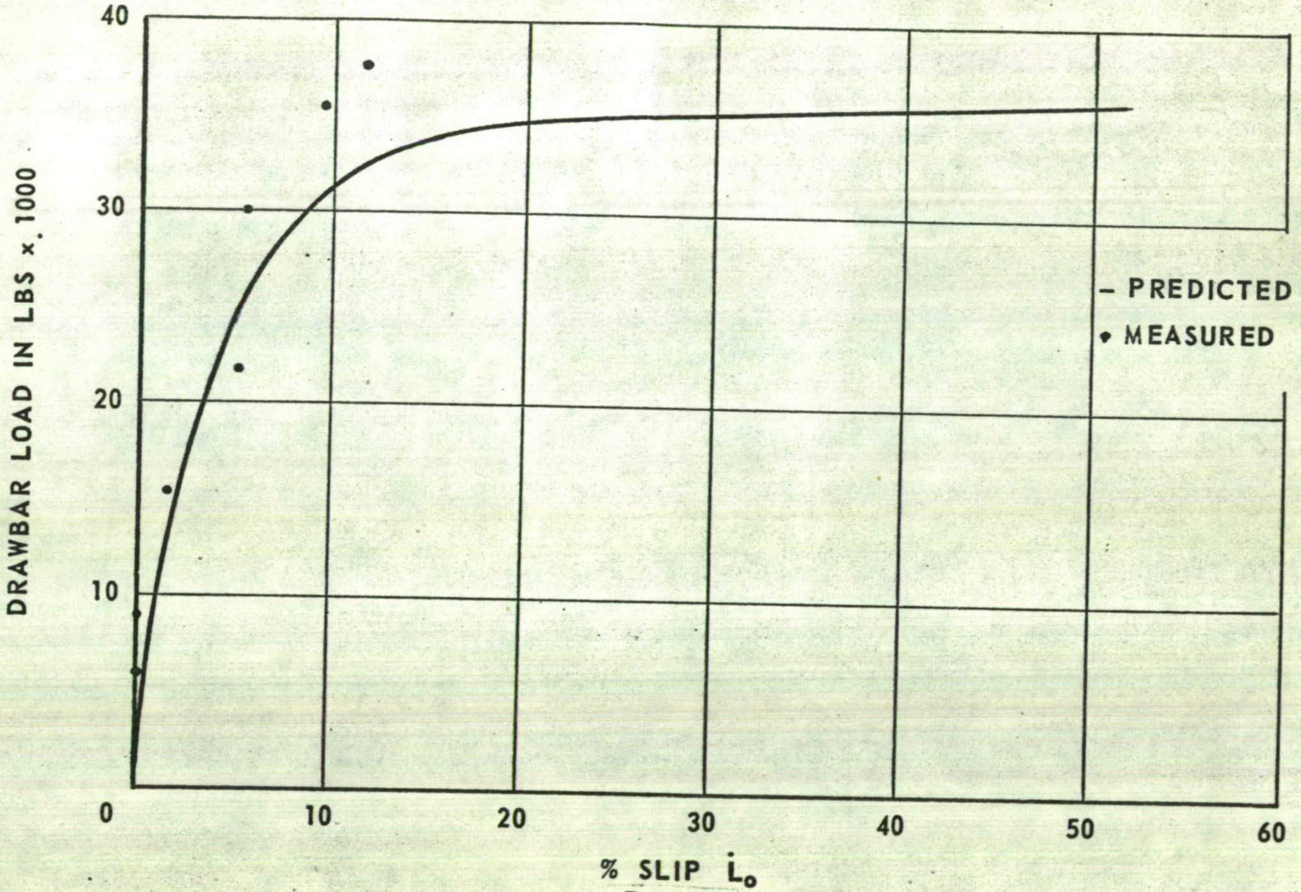


Fig. 39

AD ______________ Accession No. ______________

Components Research and Development Laboratories, U. S. Army Tank-Automotive Center, Warren, Michigan
MOBILITY ENVIRONMENTAL RESEARCH STUDY ONE-PASS PROGRAM by Peter W. Haley

Report No. 8785 (LL 101), January 1965, 15 pp., 39 figures, 1 table - Unclassified Report

Purpose: The overall purpose of this program was to develop a quick, accurate, prediction for one-pass performance of a vehicle operating in (1) fine-grained soft soil conditions and (2) a slippery soil layer over a hard-pan. The specific objective was to predict performance using existing analytical Land Locomotion Mechanics expressions as a datum for new relationships.

Results: Performance curves of drawbar-pull vs slip were constructed from measured vehicle tests and on the basis of measured Land Locomotion Mechanics Soil Values. Coefficient of friction values were obtained for the slippery soil layer condition in the same manner.

Conclusions: Predicted performance for the vehicles tested was within the accuracy level of 25% (that is expected from Land Locomotion Mechanics prediction techniques) for 55% of the tests conducted. The remaining 45% of the test results indicated the need, in some instances, for more realistic test techniques with regard to the vehicle test and soil data collection. A quick-data reduction procedure for predicting performance cannot be readily obtained.

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MOBILITY
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RESEARCH STUDY
ONE-PASS PROGRAM

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ENVIRONMENTAL
RESEARCH STUDY
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